INDESTRUCTIBLE AND FIRE-PROOF
(NOT SLOW-BURNING)

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GRAND P[illegible] [illegible]N 1900

U.

CENTRAL OFFICE: 1 RUE DANTON, PARIS

INDESTR ... ROOF

The Hennebique Ferro-Concrete System

GRAND PRIZE, PARIS EXPOSITION 1900

U. S. PATENTS: 611,907, 611,908, 611,909

Central Office: 1 Rue Danton, Paris

Fig. 1.—HENNEBIQUE'S APARTMENT HOUSE,
1 Rue Danton, Paris,
Entirely in Ferro-Concrete.

The Hennebique System of Ferro=Concrete

Principles==Advantages==Applications

INTRODUCTION

It is more than forty years since armored cement was invented, that is to say, when the idea was conceived of strengthening cement pipes and flower boxes by means of metallic frames.

Some few years later, reservoirs, bridges and arches in armored cement were built in Germany and in Austria; but it seems that American engineers, for the purpose of fire-proofing their buildings, were the first to apply this new invention to the construction of floorings.

There are now a great many systems of girders and floorings of ferro-concrete but when one thinks of the enormous advantages of this mode of construction, it is surprising that it is not more frequently applied by American architects and engineers, especially in such edifices the protection of which against the danger of fire is of important interest.

In the last ten years, however, construction in armored concrete has assumed great importance in Europe and we may now say that it has no longer to prove its merits, as its solidity, its durability and its fire-proof qualities are acknowledged by the generality of civil engineers and architects.

Why is it then that ferro-concrete has suddenly taken, in Europe, so important a place in the art of building? We boldly reply: "because Mr. Hennebique has given it a rational, practical and economical form."

On the 8th of August, 1892, Mr. Hennebique took out his first patent in France for ferro-concrete girders and floorings and, since that date, his business has attained a large and constantly increasing development, as may be seen by reference to the following figures:

Years	Number of Different Works Executed	Value of Contracts. Francs
1892	6	163,000
1893	41	900,000
1894	62	1,600,000
1895	127	2,500,000
1896	290	4,600,000
1897	473	8,200,000
1898	827	14,500,000
1899	1235	21,200,000

This last figure is easily explained by the large number of constructions Mr. Hennebique was commissioned to execute for the Paris exposition of 1900 and which won for him a *Grand Prize* at the exposition.

The buildings in which the Hennebique system could not be usefully applied are few in number. Foundations, piles, walls, posts, girders, floorings, staircases, roofings, reservoirs, tanks, wells, elevators, canals, bridges and foot-bridges are now made of ferro-concrete.

We propose to present in this pamphlet the principles of the Hennebique system. We will then show its advantages and review some of its most interesting applications.

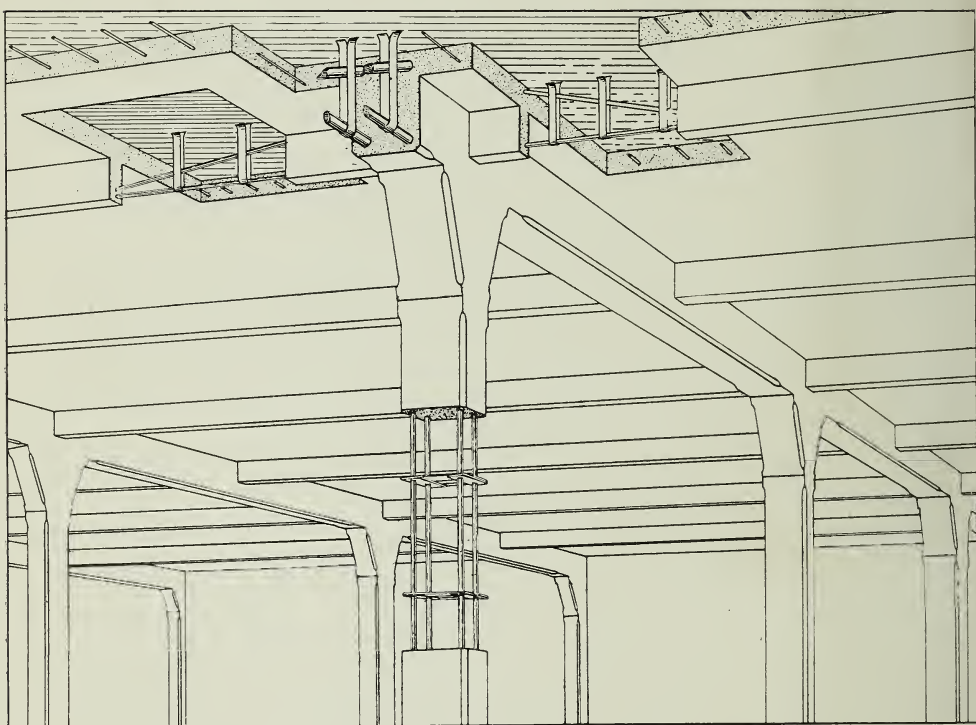

Fig. 2.—Hennebique's Floor. Disposition of Iron in Posts, Beams and Fillings.

Principle of the Hennebique Girder

On October 4, 1898, Mr. Hennebique took out a patent (No. 611,907) in the United States for "The Construction of Joists, Girders and the Like."

The girder is, in fact, the most important element in the construction of a flooring, and it was the invention of the girder which led Mr. Hennebique to make the numerous applications he has made of his system.

In order to arrive at a correct understanding of the Hennebique girder let us first examine a series of floor systems. It will then be seen by what process of scientific evolution and careful calculation Mr. Hennebique arrived at his perfected system.

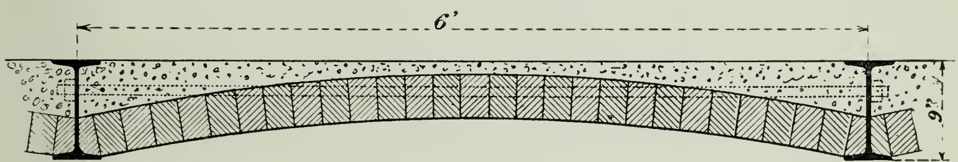

Fig. 3.—Iron and Brick Floor (not fire-proof, not water-proof).

Span of Beams, 15′
Spacing of Beams, 6′

Steel	5 lbs.	
Filling	67 "	
Weight of Floor	72 "	per sq. ft.
Superimposed Load	78 "	per sq. ft.
Total Calculated Load	150 lbs.	per sq. ft.

To begin with, let us consider an ordinary I beam and brick arch floor. Let us note, in the first place, that the brick arches add no element of strength to the iron beams, unless it be by the "bracing" which they furnish them. (Fig. 3.)

The iron beam is composed of three parts: the web and the two flanges, and each of them is destined to resist stresses of a special nature.

The bending which the beam undergoes when overburdened shows that the chords of the upper flange are subjected to strains of compression while the chords of the lower flange are subject to tension strains.

The function of the metal which constitutes the web of the beam is to unite the two flanges and enable them to combine their respective powers of resistance so as to withstand the bending of the beam. This metal is subjected to a tendency to longitudinal slipping of the chords with reference to each other.

But this is not all. Shearing stresses occur near the supports and the whole section of the beam is thus called upon to resist these stresses. In most cases the section of the beam employed is more than sufficient to supply the necessary resistance to these forces.

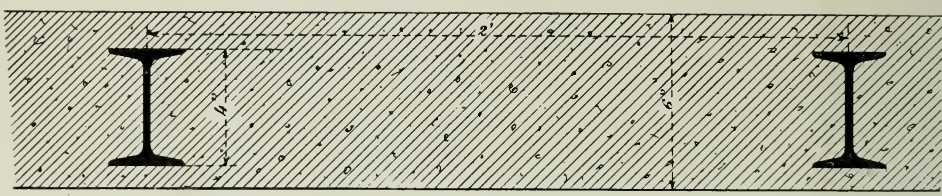

Fig. 4.

Now let us consider another flooring composed of I beams but the filling of which is composed of ferro-concrete cement. We will thus obtain an excellent construction, which is fire-proof and water-tight. (Fig. 4.)

We think that no competent engineer will refuse to admit that here, the concrete filling brings to the iron beam a supplement of strength important enough to permit our employing without danger, I beams of lighter weight than those used for the flooring we have studied previously.[1]

But we know on one side that the concrete offers considerable resistance to the stress of compression and not to the stress of traction [2] and on the other hand that this stress of traction is efficiently resisted by iron or steel.

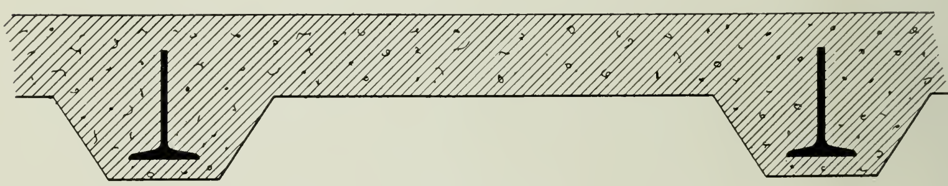

Fig. 5.

Let us, therefore, do away with the upper flange of the iron beam and suppress at the same time part of the concrete in the lower face of the floor; we do not diminish to any great extent the force of resistance of the flooring, while we leave to it its fire-proof quality. (Fig. 5.)

Mr. Hennebique went further: he suppressed also the web of the beam, and substituted for the lower flange simple bars of round iron. He succeeded thus in realizing a considerable economy in the cost of the construction we have described, while not taking away any of its qualities of solidity and incombustibility.

[1] Experience has proven this and theory confirms it as follows: We have brought to the upper flanges a supplement of resistance by the addition of the concrete. By this single fact we have raised the neutral axis of the profile; we have augmented the leverage of the tensile chords and consequently increased the beam's moment of resistance to tension.

[2] For cement mortar, 1 to 3, the ultimate tensile strength is 300 pounds per square inch, and the ultimate compressive strength is 3000 pounds per square inch.

Figure No. 6 represents the section of the beam and the filling which is indissolubly bound to it. Girder and filling are both formed of concrete of Portland cement, moulded on the spot. At the lower part of the girder the bars of round iron, of which we have just spoken, are shown.

The stress of compression which, in the I beam, was resisted by the upper flange is now opposed by the prism of concrete which constitutes the filling.[1]

The stress of tension is resisted by the bars of round iron that have taken the place of the lower flange of the I beam. As we have seen, these two parts of the girder must be indissolubly connected by a web which transmits the compressive stresses to the chord in tension and which opposes the longitudinal slipping.

Concrete is the most economical material for such a union, the more so as it envelopes the bar and so protects it from all exterior influences. But the concrete alone will not suffice for this task, for in certain cases it might be subjected to stresses of traction or of slipping for which it is not adapted. For resisting such forces, Hennebique calls for a series of stirrups distributed along the beam

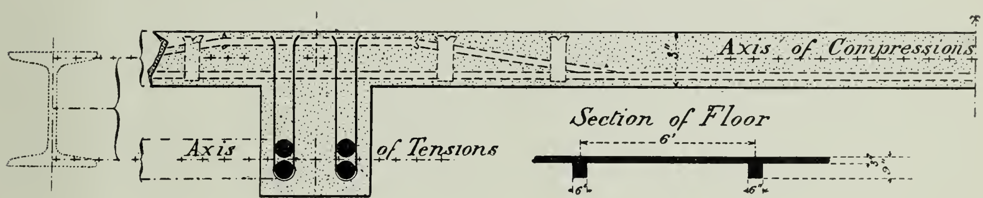

Fig. 6.—Hennebique's Floor.—Fire-proof—Water-proof.

Span of Beams, 15′
Spacing of Beams, 6′

Steel	3 lbs.	
Concrete	45 "	
Weight of Floor	48 "	per sq. ft.
Superimposed Load	78 "	per sq. ft.
Total Calculated Load	126 lbs.	per sq. ft.

connecting the bars with the upper part of the concrete. The stirrups, incased in the concrete, constitute the web of the girder by completing it.

These stirrups which we represent in figure No. 8 are made of simple hoop-iron bent in a U shape around the round iron.

Numerous experiments have been made to show the utility of these stirrups. Two exactly similar girders were recently constructed for test purposes by Mr. Hennebique, one being provided with stirrups, the other with none. Both were loaded until they began to show cracks. The stirrupless girder was the first to give way. By continuing to add to the load, there was seen what we show in figure No. 7.

[1] Numerous experiments have been made in Germany and Austria on blocks of mortar and concrete taken from bridges in concrete or armored cement in process of construction, and the figures of resistance to compression vary from 200 to 300 kilos per square centimetre (2800 to 5000 lbs. per sq. inch). (Candlot-Ciments et Chaux hydrauliques.)

In the stirrupless girder the concrete broke off in plates underneath the iron leaving it bare. But with the same load the Hennebique girder showed only normal fissures perpendicular to the axis. It is clearly demonstrated that this strengthening of the girder more than compensates the expense of iron and labor occasioned by the placing of stirrups.

It should be borne in mind that the trussing of the Hennebique girdings is formed solely of the stirrups and round iron bars. This round iron is easily procured; it has more resistance than all other profiles, the areas being equal. It is true that it presents the smallest surface as compared with other irons having the

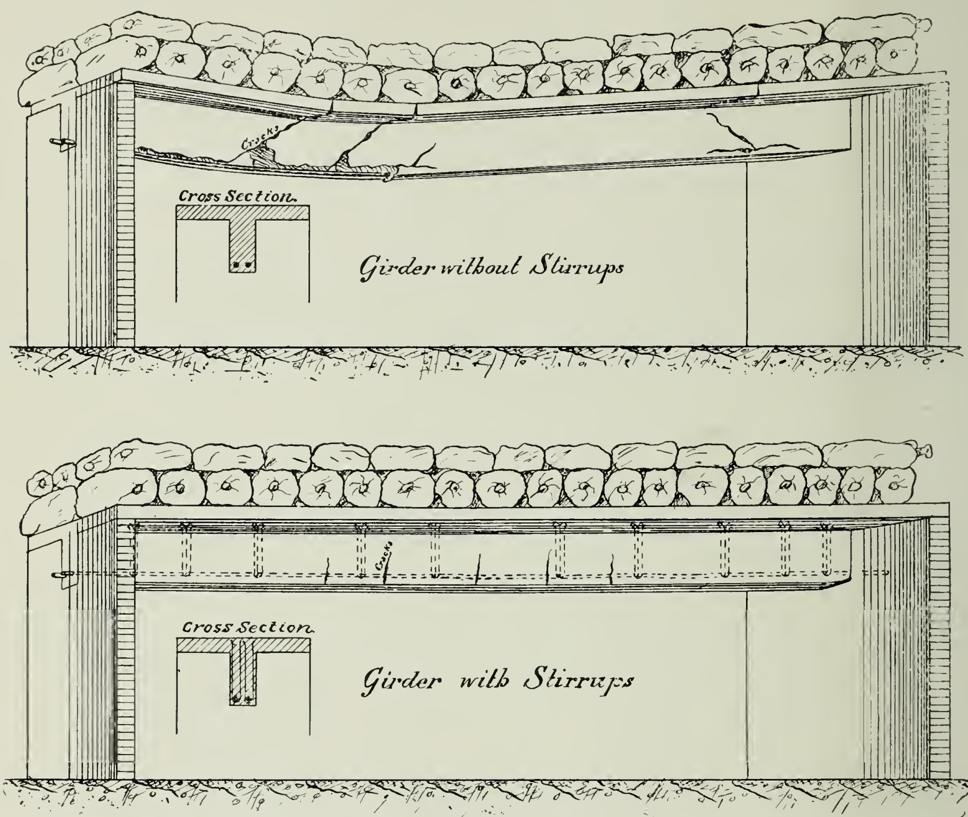

Fig. 7.

same weight per lineal foot, but, as we will show, its adherence is more than sufficient. It has, besides, this advantage that it does not occasion in the concrete mass the small cracks so often caused by the sharp edges of flat or square bars.

We have said that the girder is subjected, in the vicinity of the supports to shearing stresses which tend to clip it. Figure No. 8, which represents the girder in elevation shows that above the supports we have a quantity of metal equal to that which is in the center of the girder and that this metal is symmetrically distributed through the section. It is ascertained by computation that most of the time this metal is amply sufficient to resist the stresses of shearing and the resistance of the concrete counts for nothing.

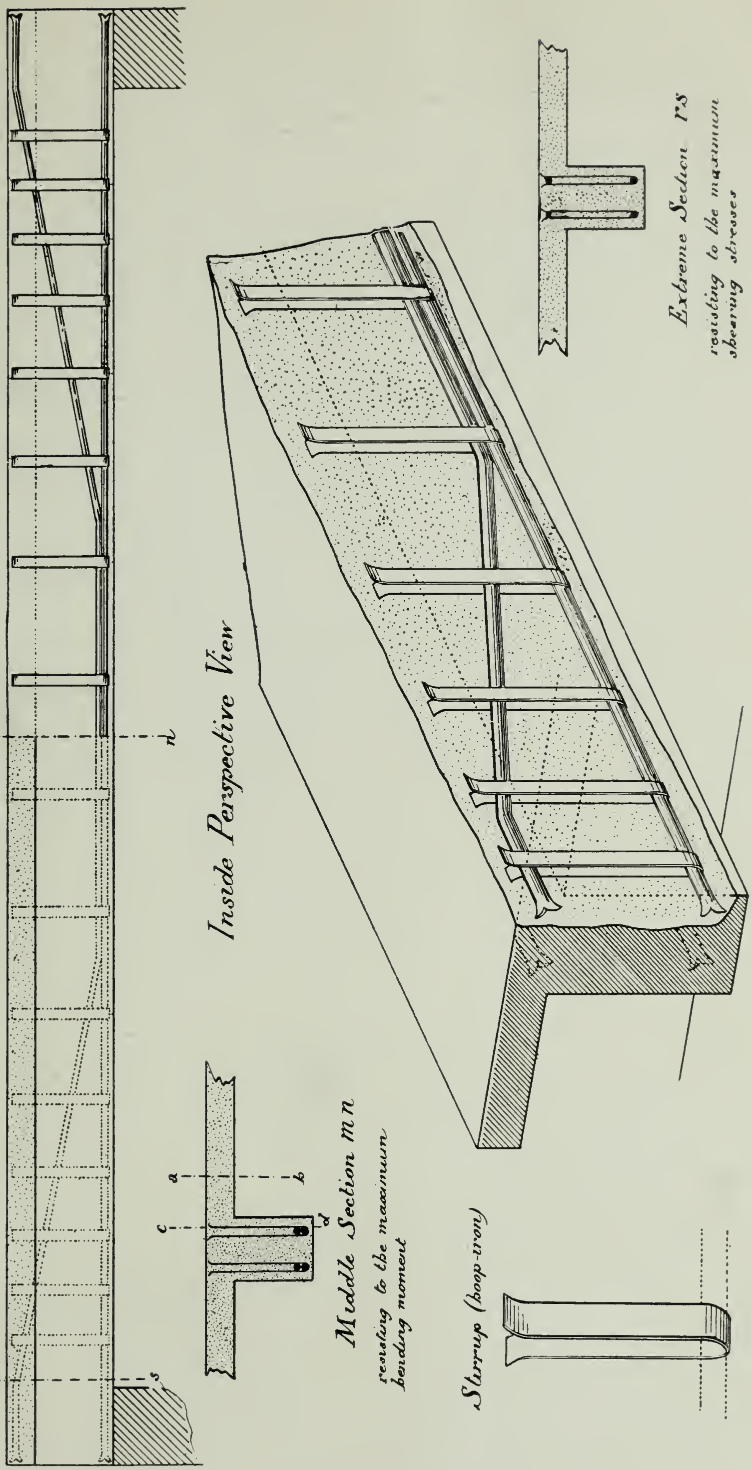

Fig. 8.—Hennebique's Girder.

It will be observed that it was deemed expedient to place one-half of the round iron bars in the median section and then to turn them up obliquely to reach the upper part of the girder. They are, indeed, no longer necessary to resist the stresses of tension which diminish progressively as one moves away from the middle of the girder; and they come to oppose the shearing stresses which, on the contrary, increase when one comes nearer to the supports.

The same figure shows, besides, that the stirrups are the closer to one another the nearer they are to the supports. The reason for this is the following:

By subjecting a stirrupless girder to increasing loads until they come to break, Mr. Hennebique observed that the cracks produced in the concrete close to the supports were not vertical but oblique and that the inclination of these cracks was the greater as they were the more distant from the supports.

This observation led him to multiply the stirrups at the ends of the girder in order that the point of breaking should meet a great number of stirrups which would present an opposition to such breaking.

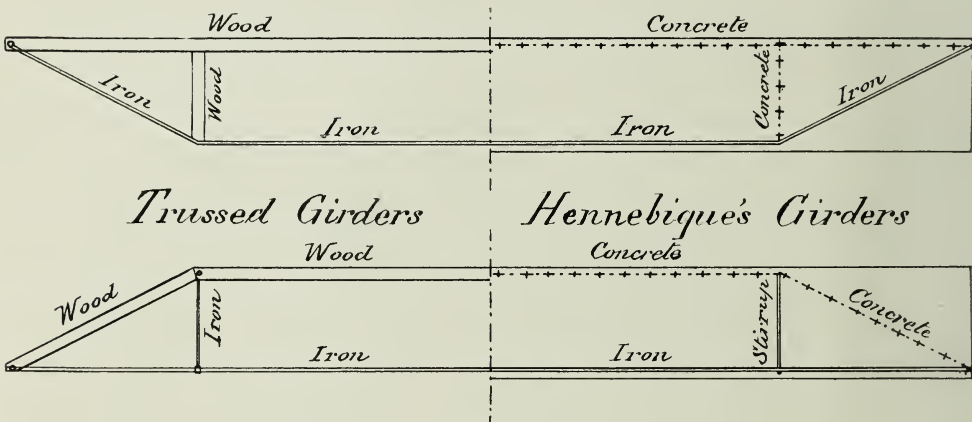

Fig. 9.

The oblique tie-rods connected with the stirrups oppose also the longitudinal slipping of the girder's chords. They form together unalterable triangles analogous to those we see in trussed girders composed of wood and iron tie-rods.

In our system, ferro-concrete is substituted for wood.

Hennebique's ferro-concrete is made up with mixtures of varying proportions of the best slow-setting Portland cement, coarse siliceous sand and clean gravel or broken rock. Where the latter is used its dimensions vary between $\frac{1}{2}''$ and $1+\frac{1}{2}''$. The quantities of the component parts used in making up the mortar depends upon the character of the work for which it is to be employed. The weight of cement used varies between 10 and 25 pounds per cubic foot of beton (concrete). Either iron or soft steel rods are used in connection with the beton.

It is characteristic of the Hennebique system that the wooden moulds for all work are first set up in place after which the ferro-concrete is laid and tamped therein.

It will therefore be seen that, with heterogeneous materials, Mr. Hennebique constructs girders whose every part resists in a perfect manner the stress of trac-

tion, the stress of compression and shearing and bending stresses. Moreover he reduces to a minimum the quantity of metal used, by dispensing with it wherever there are only stresses of compression to be resisted, the ferro-concrete being fully able to do this task.

It is needless to state that the principle hereinbefore described may be applied to the manufacture of any suitable girders or joists for ceilings or floors and, in fact, to any constructions formed of beton strengthened with metal, which, as regards the strains which they will support, may be likened to girders placed on supports or incased in masonry. It is also understood that according to the dimensions of the girder, the transverse section of which is not necessarily rectangular, the number of bars 1 and 2 placed in the same vertical plane may vary.

Pillars, columns, walls and partitions as well as vaults and arches are made of armored beton according to this same Hennebique system, which consists in using

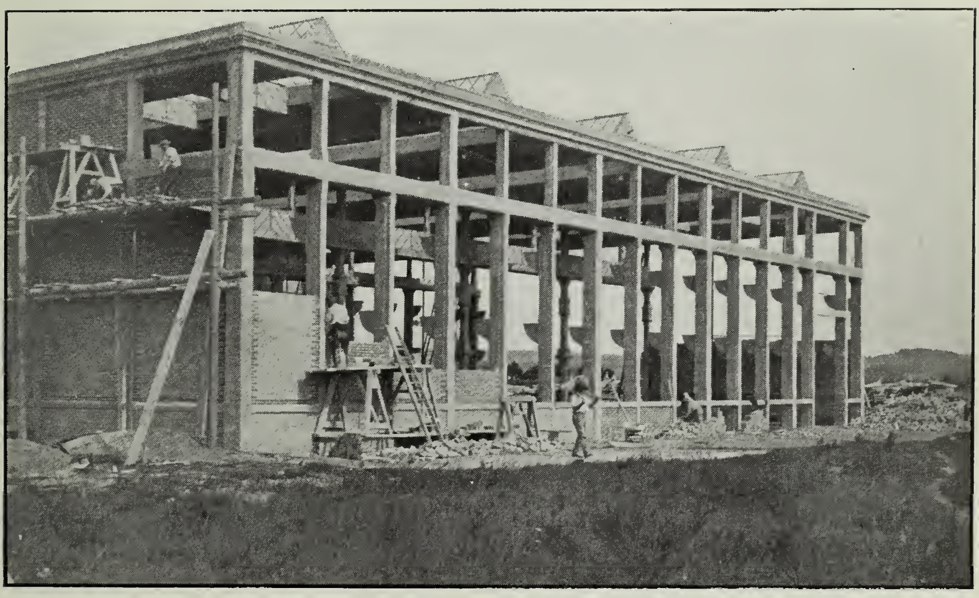

Fig. 10.—Factory Building at Epinal, France.
Construction of the Brick Walls between Ferro-Concrete Posts.

round iron bars wherever tension stresses occur and to bind them by means of stirrups (or straps) to the mass of the concrete.

All rational combinations of iron and cement are based on the following *facts:*

1st. Equality of the coefficient of dilatation of iron and cement.

2nd. Great adherence between the iron and the cement.

3rd. Impossibility of the iron oxydizing, imbedded as it is in the cement.

All experiments made so far establish peremptorily these important points:

1st. It has been scientifically demonstrated by M. Durant-Claye, chief engineer of the French Ponts et Chaussées, that the coefficient of dilatation of the two materials, iron and beton, is the same up to the fifth decimal.

2nd. The adherence between iron and cement was studied by Professor Baushinger and Professor Ritter who have estimated it at 40 kgr. per cm.^{2} (570 lbs. per square inch). If it be admitted that the ultimate strength of iron is 4000 kgr. per cm.^{2} (57,000 lbs. per square inch), the resistance of a bar of round iron of diameter *d* will be: $4000\ \varpi \frac{d^2}{4}$

If this bar be incased in beton the adherence of the beton to the iron, for a length l will be $40\ \varpi\ ld$.

By equalizing these two expressions we find $l = 25$ d.

That is to say if the bar of round iron has a length equal to more than 25 times its diameter it will break before it can separate from the beton that incases it.

3rd. The third point is perhaps the most important. Our construction is composed of iron or steel and concrete of Portland cement.

It is generally acknowledged that this concrete is absolutely indestructible, that it resists the disintegrating effect of air, of moisture, of water and steam, and even of sea-water. But is the metal imbedded in the cement also preserved from injury? Experience proves that it is.

The first Hennebique floors, constructed twenty-five years ago, are still standing.

This point is so important that, for the purpose of removing any possible doubt, Mr. Hennebique recently resolved to urge an official inquiry into the preservation of iron in cement concrete. This inquiry was held at Grenoble (France) where there is a canalization of one foot internal diameter constructed in 1886 and which had borne for the past 15 years, a pressure of 75 feet of water.

The mayor of the city of Grenoble authorized Mr. Hennebique to tear up and examine this canalization, which was done on February 2, 1901. It was ascertained that the iron contained in the walls of concrete was intact. The duration of the ferro-concrete depending upon the duration of the iron employed, it follows that the duration of the concrete is without limit.

Here is, moreover, the test of the report of inquiry which was then drawn up:

"*City of Grenoble.*"

"*Official Inquiry regarding the preservation of Iron in cement concrete.*

The City Administration ordered the construction, in 1886, of a piece of ferro-concrete water-conduit of a length of 330 feet.

The pipes have resisted and still resist the normal water pressure of 80 feet head. The length of the single pipes is 6 ft. 3 ins., thickness is $1\frac{3}{8}$ ins., interior diameter is 12 ins.

The iron skeleton is formed by 30 longitudinal rods $\frac{1}{4}$ in. diameter and one interior spiral 5/32 in. wire, one exterior spiral $\frac{1}{4}$ in. wire.

The frame of the pipes weighs 88 lbs. The pipes are connected together by armored cement rings; the metal employed was the iron of commerce, not galvanized but black.

On the 2nd of February, 1901, the above described conduit was raised up again over a length of 16 ft. Two of the joint rings were broken so as to set free two lengths of pipe which were covered with 3 ft. of earth.

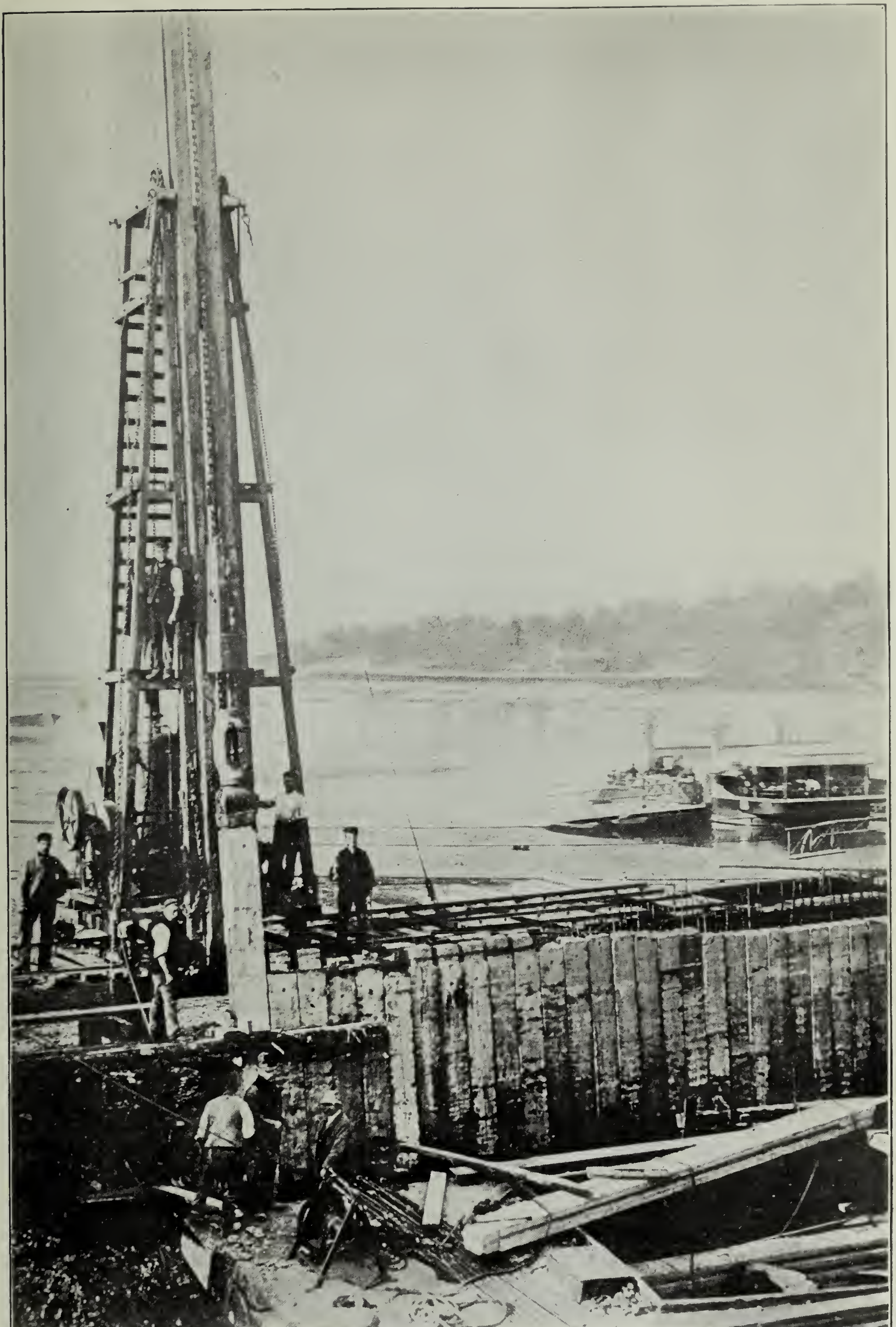

Fig. 11.—Driving of Ferro-Concrete Piles and Sheet-piles, Southampton, England.

A close examination of the pieces dug up has established the following facts:

1st. The irreproachable state of preservation of the pipes, in which there was revealed the existence of a slight calcareous deposit, about 1/16 in. thick. The pipes do not show the least fissure, either inside or outside.

2nd. There exists no trace of oxidation of the iron. The binding-in wire which connects the helix screws with the longitudinal irons is absolutely free from oxidation.

3rd. The adherence between the metal and the cement mortar, constituting the body of the pipe, was such that they would only be separated by heavy blows from a sledge-hammer despite the slight thickness ($1\frac{3}{8}$ in.) of the pipes.

Fig. 12.—Babcock & Wilcox Foundry, at Paris. Entirely built in Ferro-Concrete.

4th. Struck violent blows from a hammer weighing 3 lbs., these pipes evinced remarkable sonority, such as might be had from a cast-iron pipe of same diameter and of excellent quality.

5th. The detached fragments of the cement mortar show very sharp angles.

6th. The water-board of the City of Grenoble declare that the canalization has not required any repairs since it was set in place."

We might give a thousand proofs of the solidity of the construction on the Hennebique system. We might quote the praises given them by such eminent men as Professor Ritter of Zurich and Mrs. Considére and Rabut, chief engineers of Ponts et Chaussées of France.

The construction in Beton Armé forms a monolith; it does not show joints as in mason's work, nor scarfings, as in metallic framework. This is what constitutes its strength; it is also the reason why it equally offers great security. In fact, during the numerous experiments that have been made with a view to breaking the Hennebique girders, it has been observed that these constructions never give way suddenly but, on the contrary, long before the final breaking of the tested pieces, the beginning of the disintegration is indicated by very apparent cracks in the concrete. A like security cannot be had where the construction is of wood, stone or iron.

Moreover, Mr. Hennebique has never undertaken the least important construction without guaranteeing its solidity. If, for instance, a floor is calculated to bear a superimposed load L per square foot he subjects that floor to a test load equal to $1\frac{1}{2}$ L, and pledges himself that the bending of the girders shall be less than 1/800 of their span.

Finally, can any doubt be entertained of the strength of Hennebique's ferro-concrete when it is known that piles of 45 feet 14 ins. $\times$ 14 ins. have been made of it, which piles were driven with a $2\frac{1}{2}$-ton ram. (Cold Storage Plant at Southampton for account of the London & South-Western Railway Co.)

For the theoretical study and calculations of resistance of the ferro-concrete, Hennebique system, we refer the reader to the detailed studies made and published by Prof. Ritter (Schweizerischen Bauzeitung, 1899, Band XXXIII, Nos. 5, 6, 7) and Engineer Considère of Ponts et Chaussées (Le Génie civil, No. 8 du 4 février, 1899. Comptes rendus de l'Académie des Sciences de France).

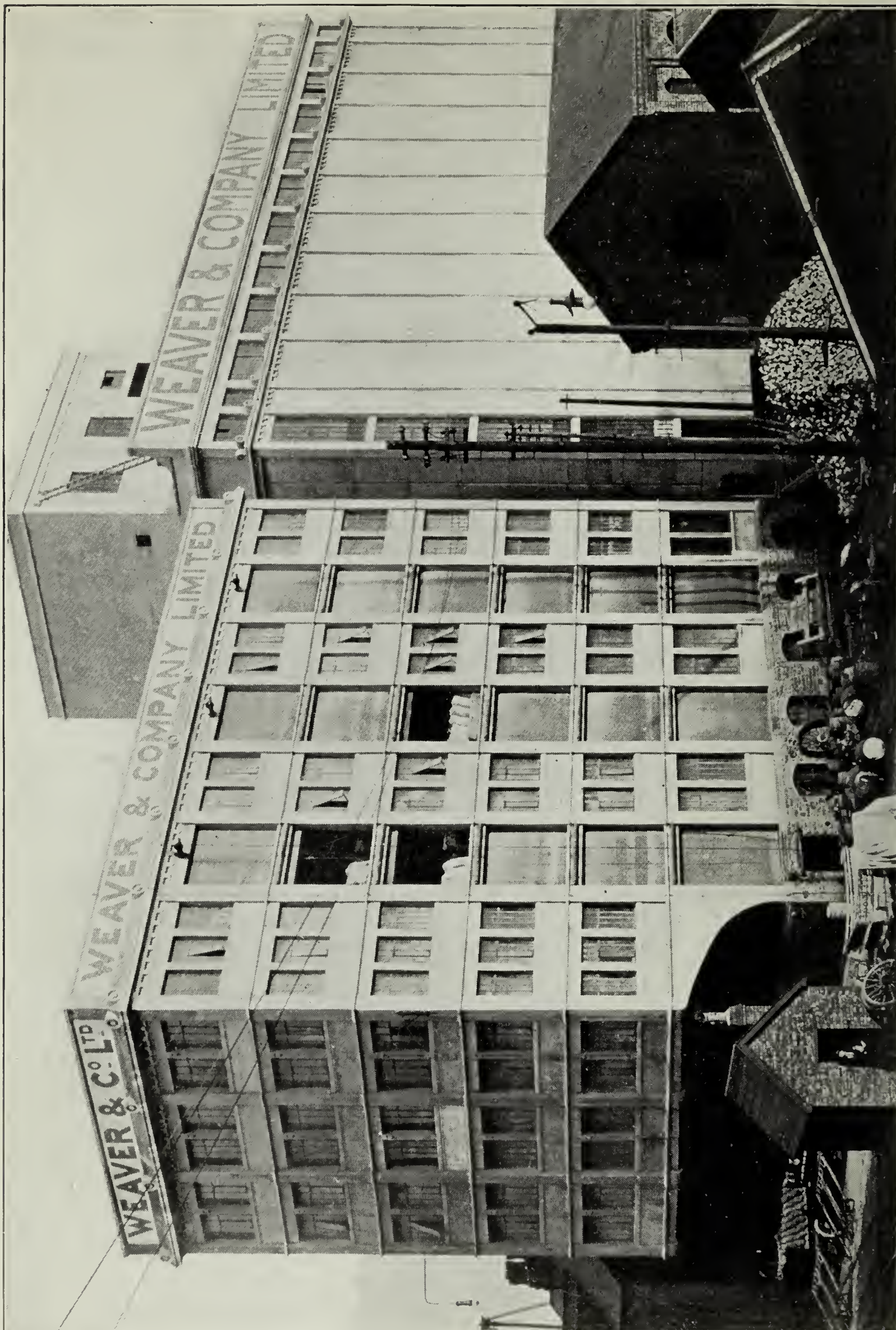

Fig. 13.—Flour Mill and Grain Elevator, 7000 tons capacity, at Swansea, England. Entirely built in Ferro-Concrete.

Advantages of the Hennebique System of Ferro-Concrete Construction

Fire-Proofing.

The principal quality of ferro-concrete is that it is fire-proof. Columns, girders, floors, stairways of ferro-concrete are unalterable by the action of fire.

It is now well known that iron or steel constructions resist the action of heat in cases of trifling fires or at the beginning of a conflagration, but fail to do so when the fire has attained a certain fierceness. Iron beams heated to a high temperature lose all resistance and fall, dragging down the walls with them.

Conclusive experiments demonstrate that quite to the contrary, concrete will bear excessively high temperatures without disintegrating and thus preserve the iron it envelops.

We will now call attention to experiments that were made at the Provincial Exposition of Ghent, 9th and 28th September, 1899. Mr. Hennebique had erected, in the gardens of the exposition, a two-story pavilion entirely built of ferro-concrete.

Tests of resistance were first made by loading the floors of the second story and of the terraced roof, by means of bags of sand. The load was equivalent to 1000 kilogrammes per square meter (about 200 lbs. per square foot). The flection of the floors, which was ascertained by means of registering apparatus, was scarcely 1 millimeter.

The lower room was then filled with wood and coke; the whole sprinkled with petroleum and set on fire. The conflagration lasted one hour and the temperature produced may be estimated at 1300 degrees F.

At the end of the first test, the temperature measured on the floor of the first story had only risen 4° F., which means that no mercantile product whatsoever would have suffered damage in this room. During the conflagration the flection of the floor attained 13½ mm. (about half an inch). The whole building was next copiously sprinkled with water which caused only a few cracks in the concrete. Two hours after the extinction of the fire and when the load was removed, the floor had risen 12 mm., so that the permanent deflection resulting from the fire test under a very heavy load was scarcely perceptible.

In order to prove that ferro-concrete which has been subjected to the action of fire was still capable of bearing the same loads as before, Mr. Hennebique again experimented on the 28th of September, this time loading the floor with 2000 kgs. per sq. meter (about 400 lbs. per square foot) and subjected it to a new conflagra-

tion which, this time, lasted two hours. The ferro-concrete successfully resisted this test.

Similar experiments were made for the French government in Paris the 14th and 20th of August, 1900. A small building entirely made of concrete was twice exposed to the action of fire after the floor had been laden with bags of sand, and it suffered no deterioration.

To sum up, the action of violent conflagrations upon constructions in ferro-concrete will necessitate only a few repairs; and the very slight conductibility of walls, of even 3½ inches thickness, makes of them absolute fire-check curtains.

Fig. 14.—Fastenings of Shaft-Hangers on Ferro-Concrete Pillars.

These fire-proof qualities of ferro-concrete constructions make them excellent risks and enable the owners thereof to obtain the lowest insurance rates possible.

Ferro-concrete is not only proof against accidental rises in temperature but may be made to resist permanent ones, as is illustrated in the construction at Luzech (France) of a lime-kiln which gives a saving of 50 per cent over kilns built of sheet iron lined with refractory brick. This lime-kiln has been in use since December 1, 1899, and continues to give full satisfaction.

Low Temperatures.

Since we are discussing the effect of temperature on ferro-concrete, we may say here that cold has no influence whatever on its resistance. In 1897 Mr. Hennebique constructed at Torino (Italy) floors for an ice factory, which are exposed on the one side to freezing temperature room and on the other to the heat of the boiler rooms. They have never shown any traces of disaggregation or weakening.

Ferro-concrete withstands in temperature in the most different climates. Numerous applications of it have been made at Cairo and in Russia (bridges, reservoirs, etc., at Ekaterinoslaw; Museum of Egyptian antiquities at Cairo).

Vibrations.

Floors in ferro-concrete offer great resistance to vibrations. Comparative experiments were made recently at Paris by the engineers of the Paris and Orleans Railroad Company, under the direction of engineer Lanna, on the floors of the electric works of the Austerlitz Station.

Two floors, one of ferro-concrete, the other of iron and brick, both having the same bearing and calculated for the same free load, were tested comparatively in order to observe the effect of shocks. The dead weights of these floors were respectively, per square foot: iron floor = 100 lbs., concrete floor = 62 lbs.

Weights of 110 lbs. and 220 lbs. were let fall on these floors and it was noted that a weight of 110 lbs. dropped from a height of $6\frac{1}{2}$ feet, produced on the iron floor vibrations of 5/16 inch amplitude, lasting two seconds, while a weight of 220 lbs. falling from a height of 13 feet on the ferro-concrete floor only caused maximum vibrations of 1/16 inch, lasting 5/7 of a second.

Thus a force four times greater gave a bend five times smaller in a ferro-concrete floor than in an iron floor whose dead weight was about one-half greater than that of the concrete floor, and the duration of the vibrations in the latter case was about one-third that in the case of the former.

It is easily seen of what importance this quality of the ferro-concrete must be for factories, workshops, bridges, etc.

Impermeability.

The ferro-concrete is impervious to water, air and moisture, for which reason it is admirably adapted for tanks, wells, etc.

Hygiene, Cleanliness, etc.

Neither insects nor rodents find shelter in ferro-concrete. They cannot attack it for such is its hardness after a few months that it is with difficulty that it can be chipped with the best steel instruments. One will readily perceive the possible applications of this remarkable propriety for hospital uses and school floors, grain elevators, piles driven into the ground or immersed and constructions in warm countries.

Vaults have been made of it in a number of banks in Switzerland and elsewhere and bullet-proof screens for target practice are being made of it. Finally it may be noted that all the great Powers are now using ferro-concrete for the protection of fortresses against shell fire.

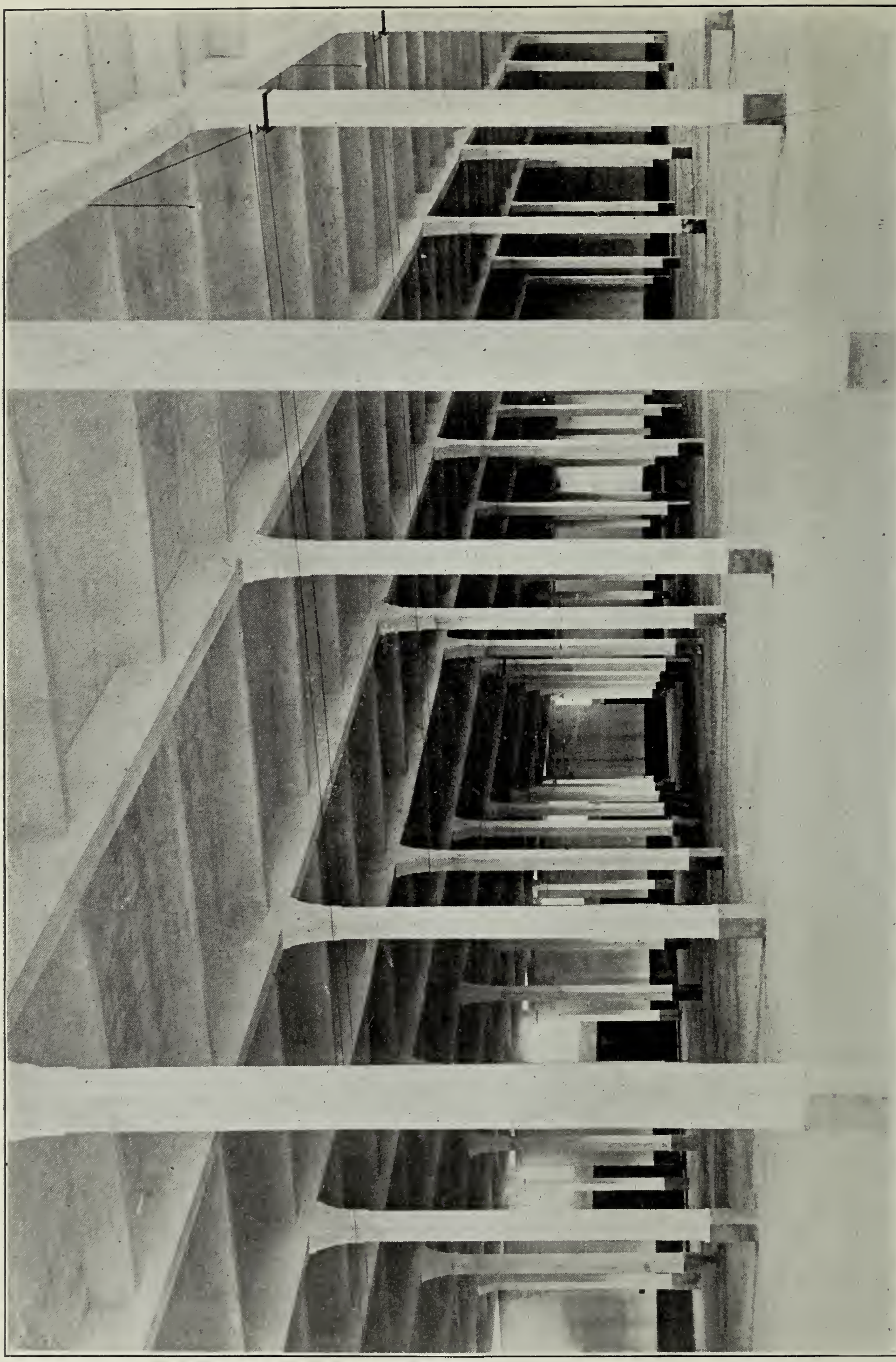

Fig. 15.—View of Floor, Beams and Pillars, Hennebique System.

Applications of Ferro-Concrete, Hennebique System

We can give here only a mere idea of the number and variety of advantageous and economical applications Mr. Hennebique has made of his system of construction. In attempting this we will adopt the following classification:

1st. Industrial constructions and lodging houses. Foundations, walls, posts, floors, cantilevers, overhangs, staircases and roofs of all kinds.

2nd. Tanks and reservoirs, grain elevators, conduits and pipes.

3rd. Bridges and foot-ways.

1st.—INDUSTRIAL CONSTRUCTIONS AND LODGING HOUSES.

Foundations.

A notable economy is obtained in the use of ferro-concrete for constructing foundation sills. It permits a diminished depth of foundation which reduces the cost of excavation and at the same time presents an economical means of distributing enormous loads over a soil that has little or unequal solidity. In this way fissures are avoided which often occur in walls of great length. (Fig. 16.)

One of the first and neatest applications of ferro-concrete was the work of underpinning the church-tower of Albert (Somme-France). This tower was in progress of building when it was discovered that it was sinking. Its foundations had been laid on a yielding soil composed of a thickness of 20′ to 30′ of soft limestone laid directly upon the turf. In five days the tower had sunk seven inches. Mr. Hennebique caused the tower to be stayed and then rested it on a sill of ferro-concrete which projected 20 feet on all four sides. The load to which the soil was subjected was thus considerably diminished and the tower was finished. It has not moved since.

In the use of piles for foundations there is an advantage in replacing wooden piles by piles of ferro-concrete which are impenetrable and unassailable by teredoes.

Advantage to be obtained through the use of ferro-concrete for the construction of jetties, wharves, moles and walls of quays.

At Southampton, for the foundations of a cold-storage warehouse, 2000 piles of ferro-concrete, 45 feet in length and 14 x 14 inches of section, were driven by means of Lacour rams weighing 3700 and 6000 pounds.

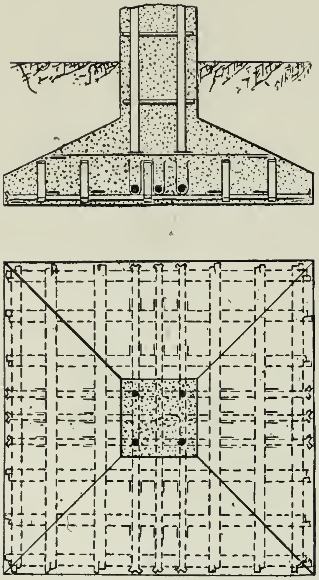

Fig. 16.—Sill of a column, Hennebique System.

We will mention also the jetty at Woolston constituted by 100 piles of 10″ x 10″ upon which the jetty platform was built. The platform carries loads equivalent to 5 cwt. per square foot. A 60-ton crane is fixed at its end.

Ferro-concrete is used in the construction of caissons or floating blocks for the foundations of sea walls. Thus the foundations of the Soutchi (Russia) quays are made of caissons of Hennebique's ferro-concrete 21′ x 14′ with 19′ of height. The thickness of the walls is 5 inches. The caisson, loaded with 6 feet of ballast, floats with a draught of 15 feet.

WALLS.

Ferro-concrete can be applied to the construction of walls and partitions and its use is particularly advantageous when great economy of space is demanded.

The apartment house of Mr. Hennebique, built at Paris, 1 Danton Street, is entirely of ferro-concrete. It contains eleven stories, counting two sub-basement floors. The annexed plan will show to what extent the use of ferro-concrete has saved space, for the external walls are seen to have but 7 inches thickness at the first story (18 centimeters). (Figs. 1 and 18.)

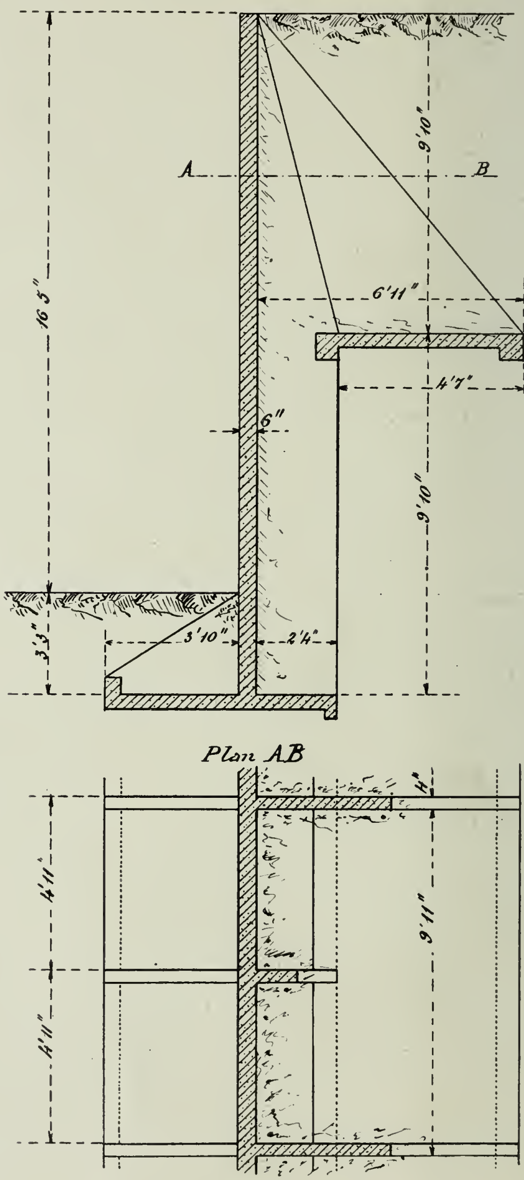

Fig. 17.—Retaining wall of the trench, Quai Debilly, Paris.

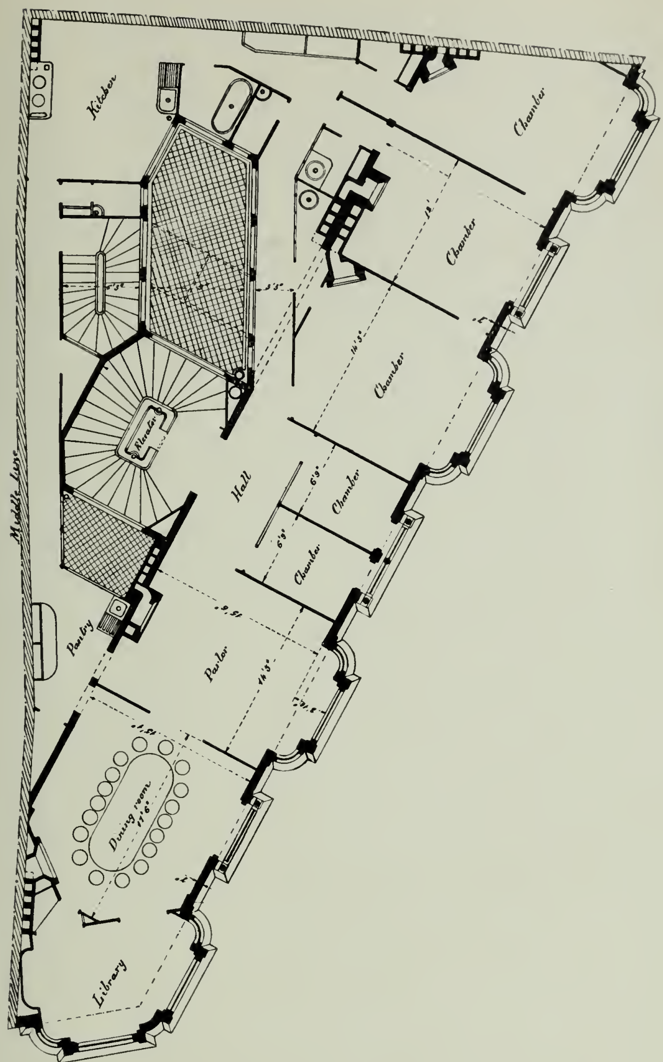

Fig. 18.—Hennebique's Apartment House. Third floor plan.

Walls of quays in jointed sheet piles of ferro-concrete procure one of the most advantageous solutions of this kind of construction.

Hennebique's retaining walls, for earth or for water, are so reduced in section that at first sight they seem rash, but if resistance of ferro-concrete to stresses of extension is taken into consideration, it will be found, as practice has demonstrated that the theory of their construction is sound. (Fig. 17.)

We give herewith the profile of the retaining wall of the Quai Debilly at the Paris Exposition of 1900. The wall was built with the approval and under the direction of the engineers of the French Ponts et Chaussées for public service. (See Fig. 35.)

Posts or Pillars.

Pillars of ferro-concrete with reduced sections, Hennebique system, will bear the heaviest loads without possible buckling. The resistance of these columns is confirmed by experiments and use. The simplest section of these pillars (figure 19) shows that the iron is placed wherever tensile strain might occur.

In buildings of several stories the pillars form a monolith from top to bottom of the construction and they are also closely connected with the floors. Transmissions may be hung on them.

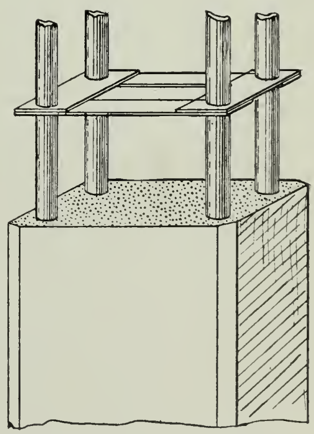

Fig. 19.—Section of a pillar.

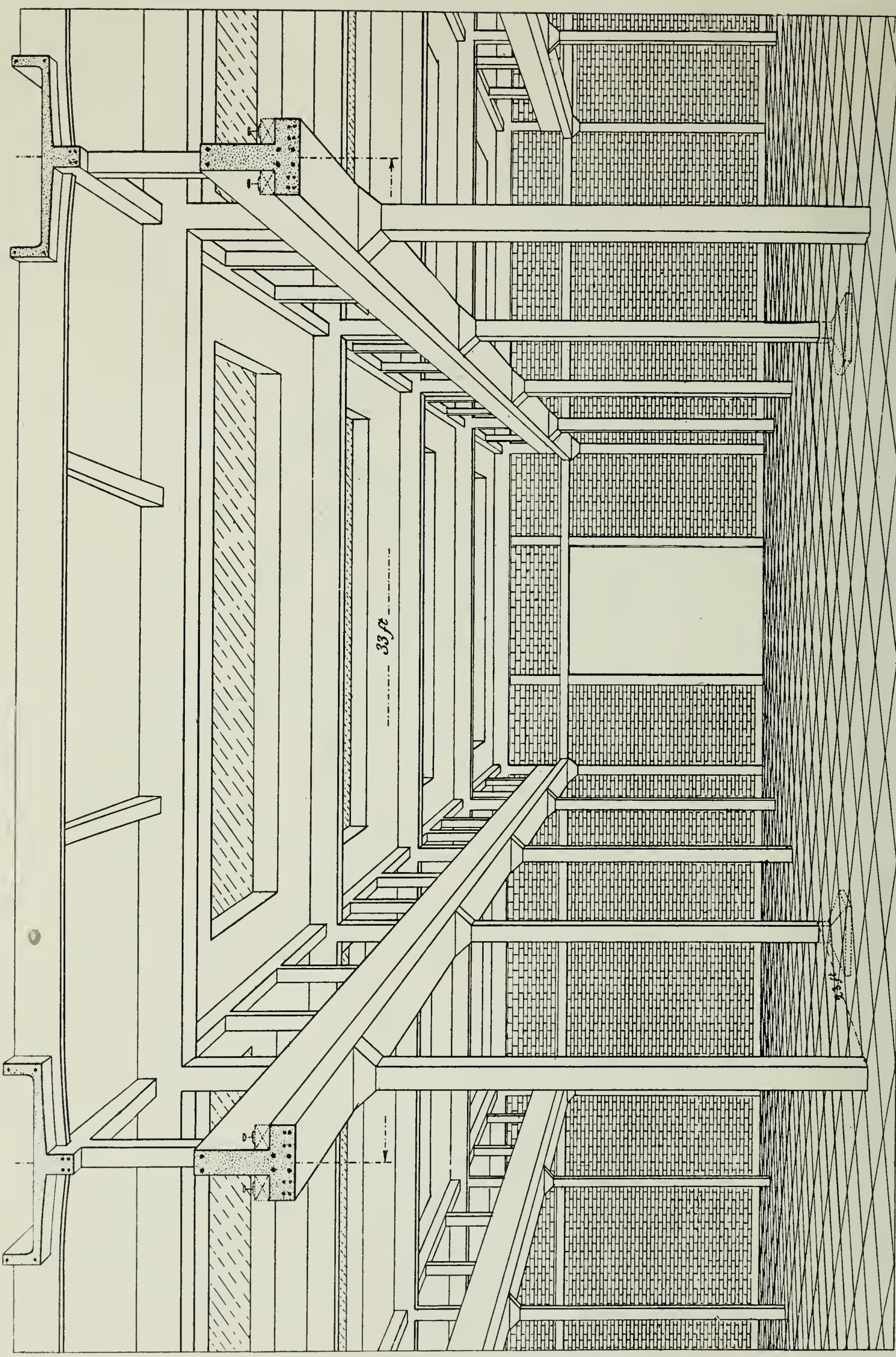

Fig. 20.—Factory Building at Epinal, France. Beams carrying a 30-ton traveling crane.

In Mr. Singrün's manufacture at Golbey (Vosges) pillars 11″ x 11″ and 20 feet in height, and with a span of 32 feet bear ferro-concrete girders on which roll travelling cranes of 30 tons. They support at the same time the flat roof of the factory and carry the shafting hangers which are bolted directly to them. These pillars are 23 feet and 33 feet between centers. The saving of space obtained through the use of ferro-concrete thus becomes self-evident. (Figs. 10 and 20.)

Floors.

We will not revert to the considerable advantages of the incombustibility, resistance to vibrations and cleanliness of ferro-concrete floors.

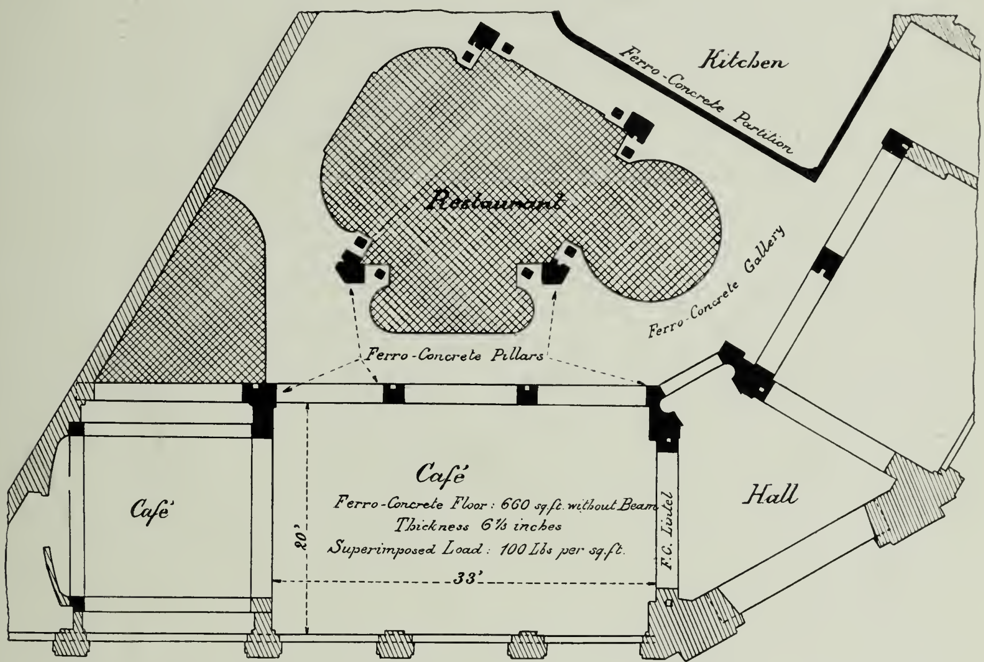

Fig. 21.—Ceiling of Café and Restaurant, property of New York Life Insurance Company, Boulevard des Italiens, Paris.

We shall certainly be asked the following questions:[1]

What is the thickness of concrete floors?

What span may be given?

Can they be given a decorative aspect and can they be ornamented?

We are going to show by examples that ferro-concrete presents, on all these points, a marked advantage over all other systems of construction.

Experience has proven that the most economical ferro-concrete floor is always of less thickness than the most economical iron floor.

[1] It is obvious that we cannot speak here of the cost of constructions in ferro-concrete and their economy. The price varies necessarily according to the cost of raw materials and localities. Each design submitted is accompanied with an estimate of cost, and it will be left to the architects and the proprietors to study our estimates.

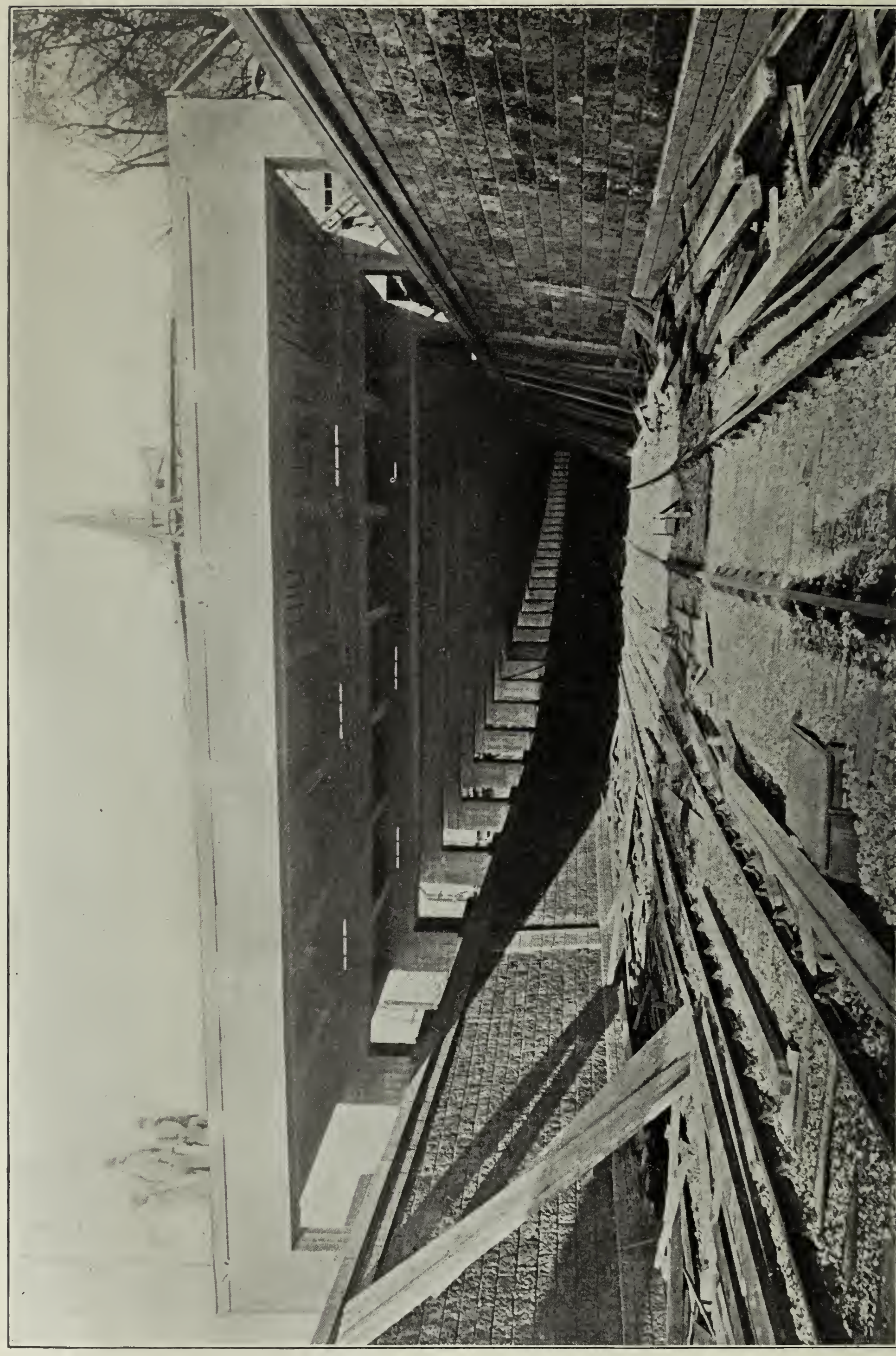

Fig. 22.—Covering of the Railroad of Moulineaux, Paris. Span, 50 feet.

All spans that may be realized in the construction of iron floors may likewise be attained in concrete building, and this always with a saving in height.

Figure 21 shows the second-story floor of the building erected in Paris for the New York Life Insurance Company. It is calculated to carry a weight of 100 lbs. per square foot and was tested with a load of 150 lbs. This floor serves as a ceiling for a café 33′ x 20′, and it was desired that the beams in this ceiling should

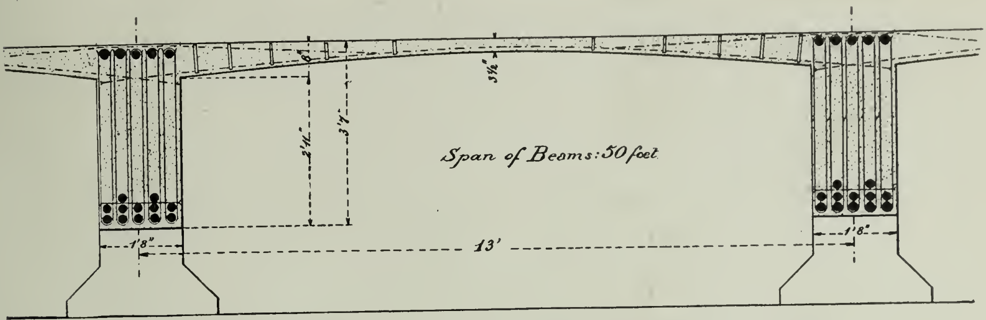

Fig. 23.—Sections of the Covering of the Moulineaux Railroad, Paris.

not be apparent. Mr. Hennebique solved this difficult problem by means of a continuous flagging of only 6½ inches thickness. If the span of this floor be well considered, it will be evident that only by the use of ferro-concrete could the architect's desire be realized.

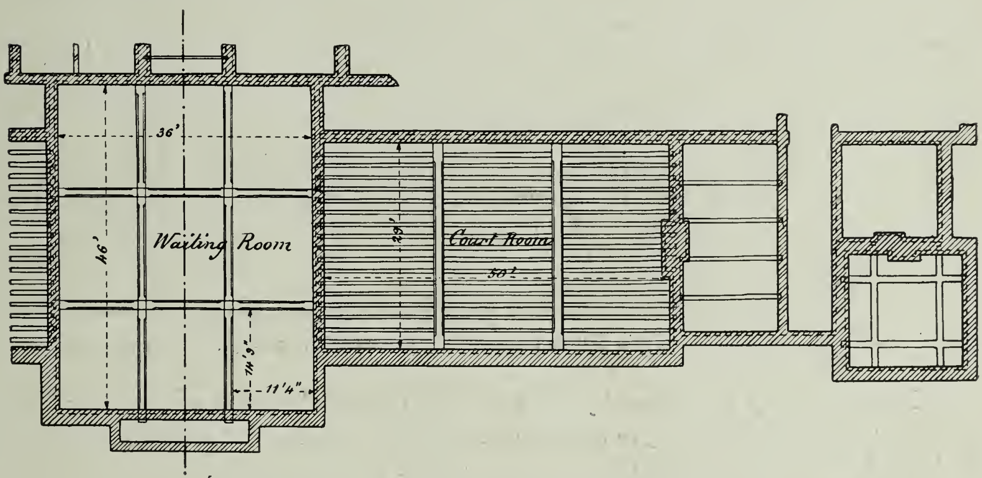

Fig. 24.—Floors of Court House, Verviers, Switzerland.

As an example of great span we will cite the covering of the trench of the Moulineaux Railroad which runs along the Seine. (Figs. 22 and 23.) Among the numerous visitors of the foreign palaces at the exposition of 1900, how many were there who knew that a railway ran under them? The floor constructed to support these palaces had a span of 52′ and was calculated to bear a load of over 200 lbs. per square foot. It was composed of girders 3½′ in height, set at 13′ to 16′ between centers and united by a ferro-concrete filling. On one occasion eleven trusses of the frame work of a palace in course of construction together with a

75-foot high crib which served to hoist them were blown down and fell upon the ferro-concrete floors, which resisted perfectly the force of impact due to the fall of these great weights. The work of covering this trench, involving the construction of 150,000 sq. feet of floor surface was completed in three months from the time of letting the contract.

Large floors with apparent beams are very often adapted for public buildings and industrial structures. In the former we easily succeed in giving them a handsome appearance, for they lend themselves to all the combinations permitted by wooden beams.

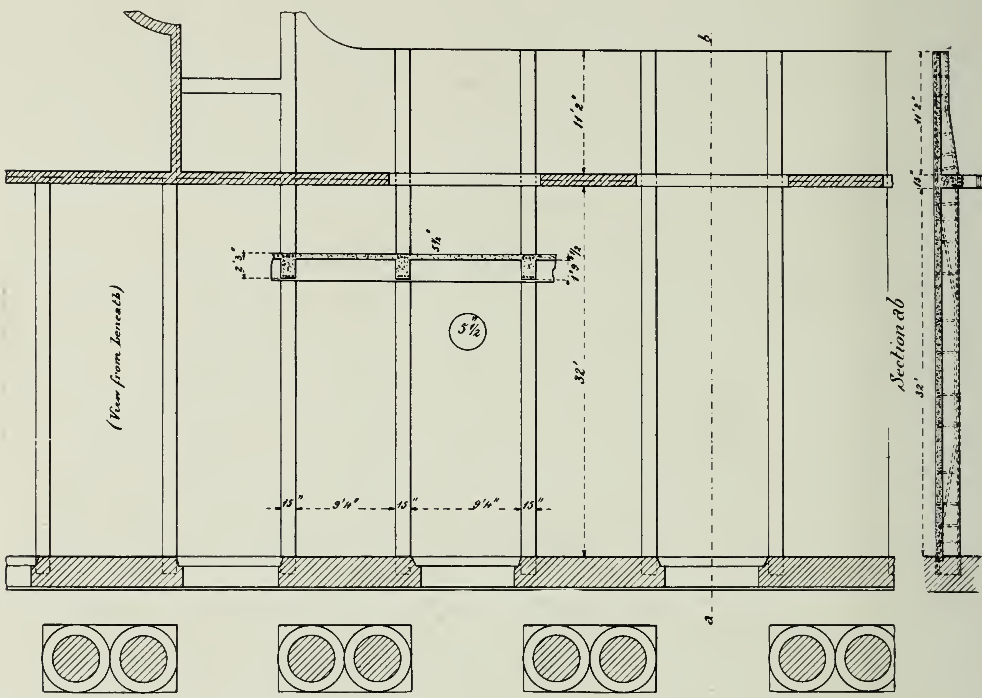

Fig. 25.—Palace of Fine Arts, Paris Exposition, 1900. Floors with gallery; overhang of 11 feet.

Moreover they can be easily decorated by means of plaster or stucco, which adheres well to the concrete; as an example we will cite the Court House of Verviers and the Lausanne Postoffice (Switzerland). (Fig. 24.)

A floor of the Palace of Beaux Arts at the Exposition of 1900 (Fig. 25) having a span of 32′ and calculated for a load of 120 lbs. per square foot was prolonged by an overhanging gallery 10′ wide, calculated for the same load. The thickness of this floor with its beams was only 26 inches. We invite attention to this disposition of a gallery which is of great advantage in the construction of theatres and concert halls, as it does away with obstructing pillars.

The theatre at Berne is constructed on this principle. It is entirely of ferro-concrete, Hennebique system. Even the stairways and the galleries are of it.

The new "Comptoir National d'Escompte" of Paris is entirely constructed of ferro-concrete, embracing floors, fronts, stairs, flat roofs and shelving.

Small Movable Buildings.

Several railroad companies, in France, have adopted ferro-concrete for the construction of small watch-boxes for signal-men, switchers, etc. These small buildings need no repairing, are very wholesome and easily transported from place to place.

Cantilevers.

Ferro-concrete being capable of resisting extension stresses permits one readily to make of this material all cantilevers that are generally in use, such as galleries, balconies and bow-windows.

We have already spoken of the cantilevers of the Beaux Arts building at the Paris Exposition (Fig. 25). Let us now mention the wharf at Nantes of 30′ overhang upon which a railway track of standard gauge is carried.

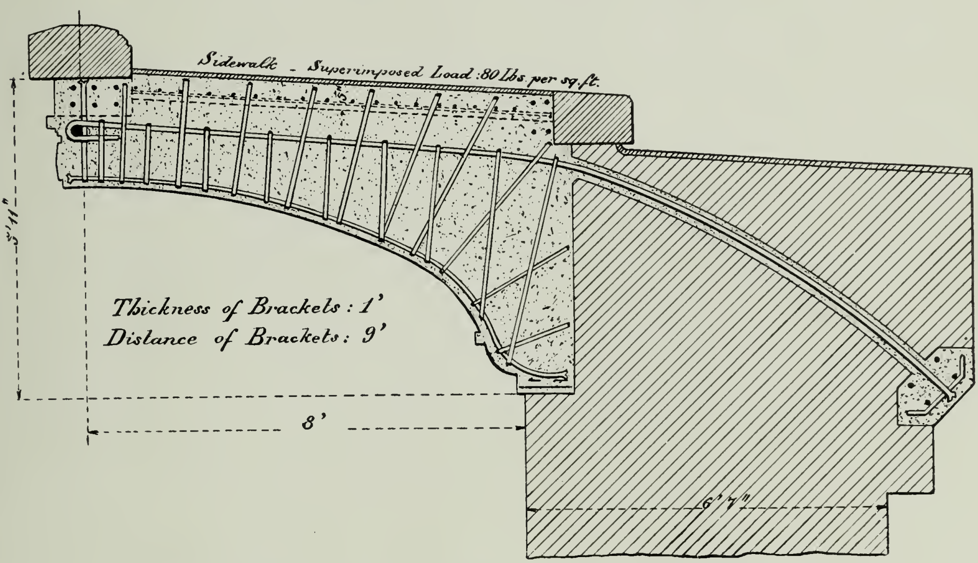

Fig. 26.—Cantilever of the Sidewalk, Boulevard Pereire, Paris.

In order to widen the circular railway of Paris along the Pereire and Lannes boulevards, ferro-concrete sidewalks and brackets, 4′ to 8′ overhang, over a length of 4000 feet, to bear a load of 80 lbs. per sq. foot were built. It must be obvious to any one that this work, intended for a thoroughfare, was subjected to the most severe tests before it was opened to public traffic. (Figs. 26 and 27.)

Architects would find great advantages with the Hennebique system in solving small difficulties in construction, especially for overhangs, balconies, etc.

Staircases.

Common sense tells us that it does not suffice to have incombustible floors but that staircases must also be indestructible by fire.

Here again ferro-concrete presents innumerable resources and admits of the most advantageous and interesting solutions. Straight staircases, winding stairs, small flights and monumental stairs are all easily constructed and decorated. We

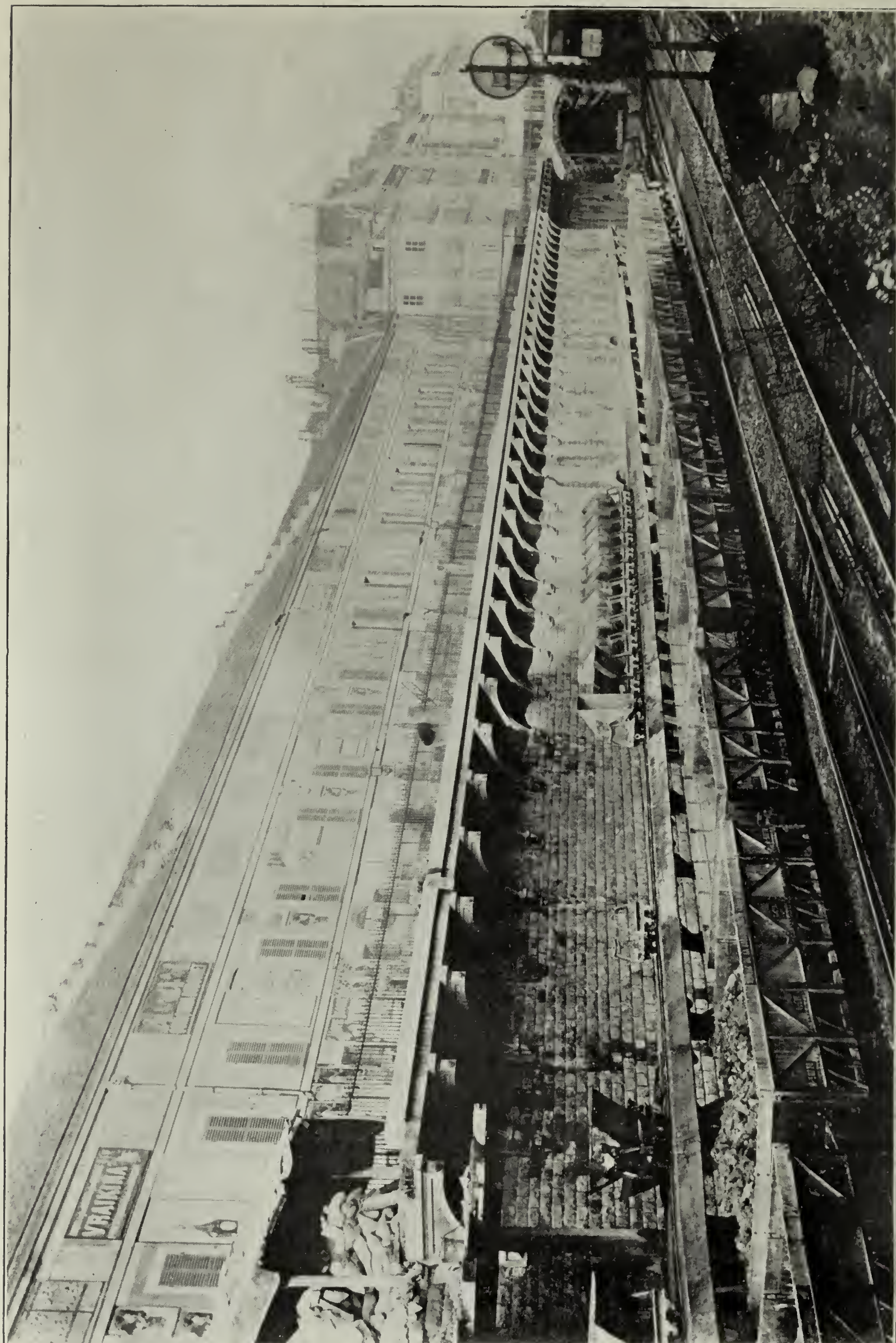

Fig. 27.—Cantilever of the Sidewalk, Boulevard Pereire, Paris.

Fig. 28.—Shed Roof in Ferro-Concrete, Boulogne Sur Seine, France.

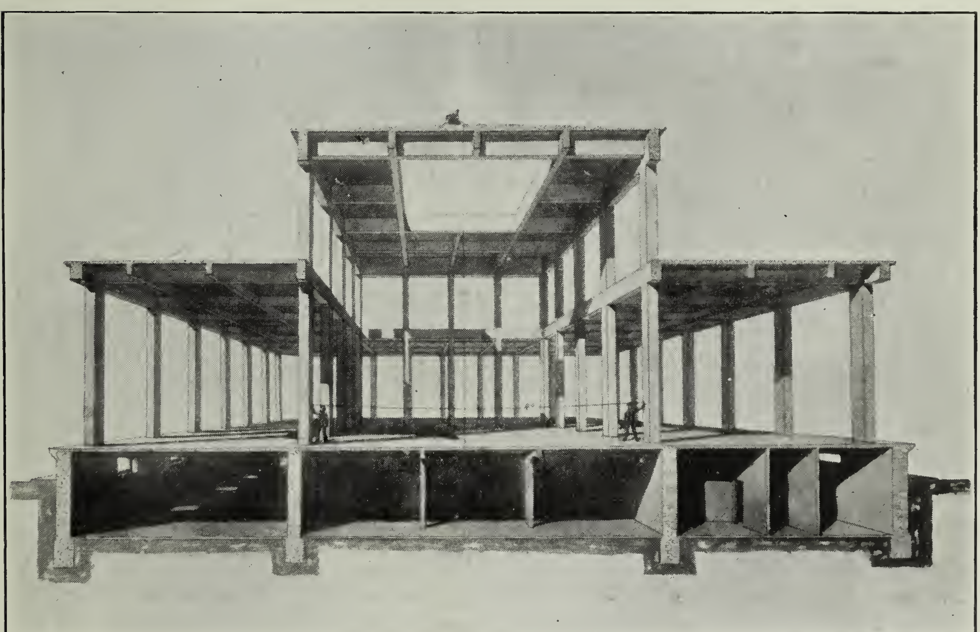

Fig. 29.—Market of Genoa.

may cite as models the staircases of the Palace of Fine Arts at the Exposition of 1900 and those of the Lausanne postoffice.

ROOFS.

All kinds of roofs are made of ferro-concrete. Figure 12 shows the summit of a roof 40-foot span in course of construction for the Babcock and Wilcox foundry

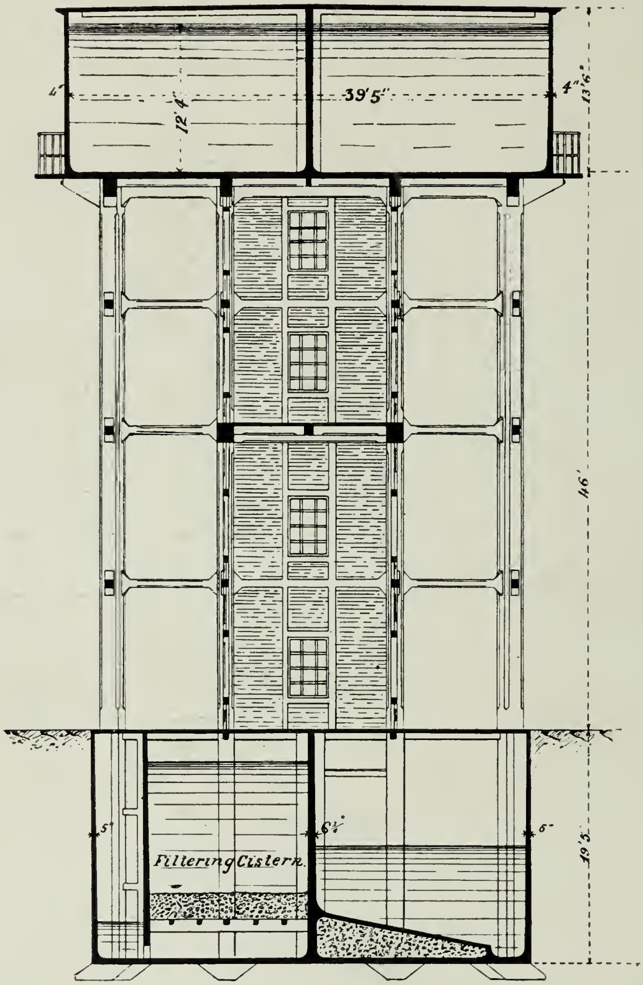

Fig. 30.—Water Tower of 120,000 gallons capacity, Billancourt near Paris.

at Courneuve (France). Figure 28 shows the shed roof of the Fontaine's mill at Boulogne sur Seine. But it is above all in the construction of flat roofs that ferro-concrete has been most advantageously used (Fig. 29). The surface of the finished roof is covered over with a layer of sand and gravel of about one foot thickness. A roof is thus obtained which possesses two highly valuable qualities: it is impervious to air and dampness and is a very poor conductor of heat; which suppresses conden-

sations in premises having high hygrometric conditions. For this reason the Chamber of Commerce of Calais (France) gave up its warehouses for storing sugar and had new ones built with ferro-concrete flat roofs (surface 54,000 sq. feet), in which the sugar is perfectly preserved.

For the same reason many cotton-mills have ferro-concrete roofs as the hygrometric state of the air plays such an important part in this industry. (Spinning mills of Lille.)

Ferro-concrete flat roofs are of great advantage for the regular lighting of large one-story factory buildings (foundries, workshops, etc.), the roofs are pierced with large rectangular openings, surmounted by a glass skylight through which an

Fig. 31.—Canal of the Simplon, Switzerland.

absolutely regular light falls (Mr. Singrün's manufacture at Golbey, France). (Figs. 10 and 20.)

Ferro-concrete is also adapted for the construction of cupolas; that of the Vichy casino has a diameter of 90 feet.

2nd.—RESERVOIRS, CANALS, GRAIN ELEVATORS.

Pipes, tanks, reservoirs, etc., were the first application of ferro-concrete. Mr. Hennebique has built every kind of reservoir, covered and open; cisterns, sunken, standing upon or elevated above the ground.

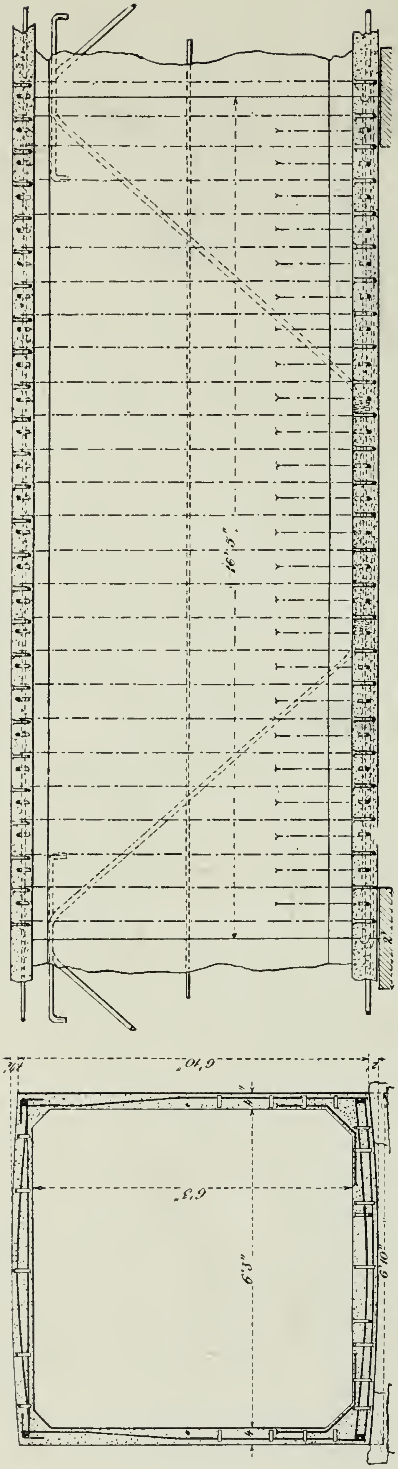

Fig. 32.—Sections of the Canalization of the Simplon, Switzerland.

For instance the reservoirs constructed at Billancourt near Paris (fig. 20) have a capacity of 120,000 gallons. The inner diameter is of 40′, the inverted arch of the reservoir is situated at the height of 46 feet and the total height of the edifice in ferro-concrete is 80 feet, of which 19 are below the surface of the ground, making the total height above ground 61 feet. The inner surfaces of basins or ditches may also be lined with ferro-concrete making them thus absolutely water-tight.

Canals.

While canals in ferro-concrete of various systems have been made everywhere, we cannot resist the pleasure of describing the canalization of the Simplon, executed in 1899, under the direction of the Engineer De Mollins, Hennebique's agent at Lausanne, Switzerland. (See Figs. 31, 32 and 41.)

The motive power required for perforating the Simplon and for lighting the works of the tunnel was about 6000 H. P. This was obtained by utilizing a part of the water supply of the river Rhone. The discharge utilized was 2113 gallons per second. This same motive power will serve, later, for the ventilation, lighting and, perhaps, for the traction motive power to be used in the tunnel. The problem was to construct a canal 9800 feet long, which would be prolonged by a forced conduit in sheet iron 5600 feet in length. But this canal, to the physical conditions involved, presented great difficulties in its execution as it first passed along a mountain side, then through a plain covered with heaps of fallen rock, rubbish, etc.

It was at first proposed to construct it of wood and the cost was estimated at 85 francs per meter. It was then that a canal in ferro-concrete was proposed, at 100 francs per linear meter, which was accepted by the company.

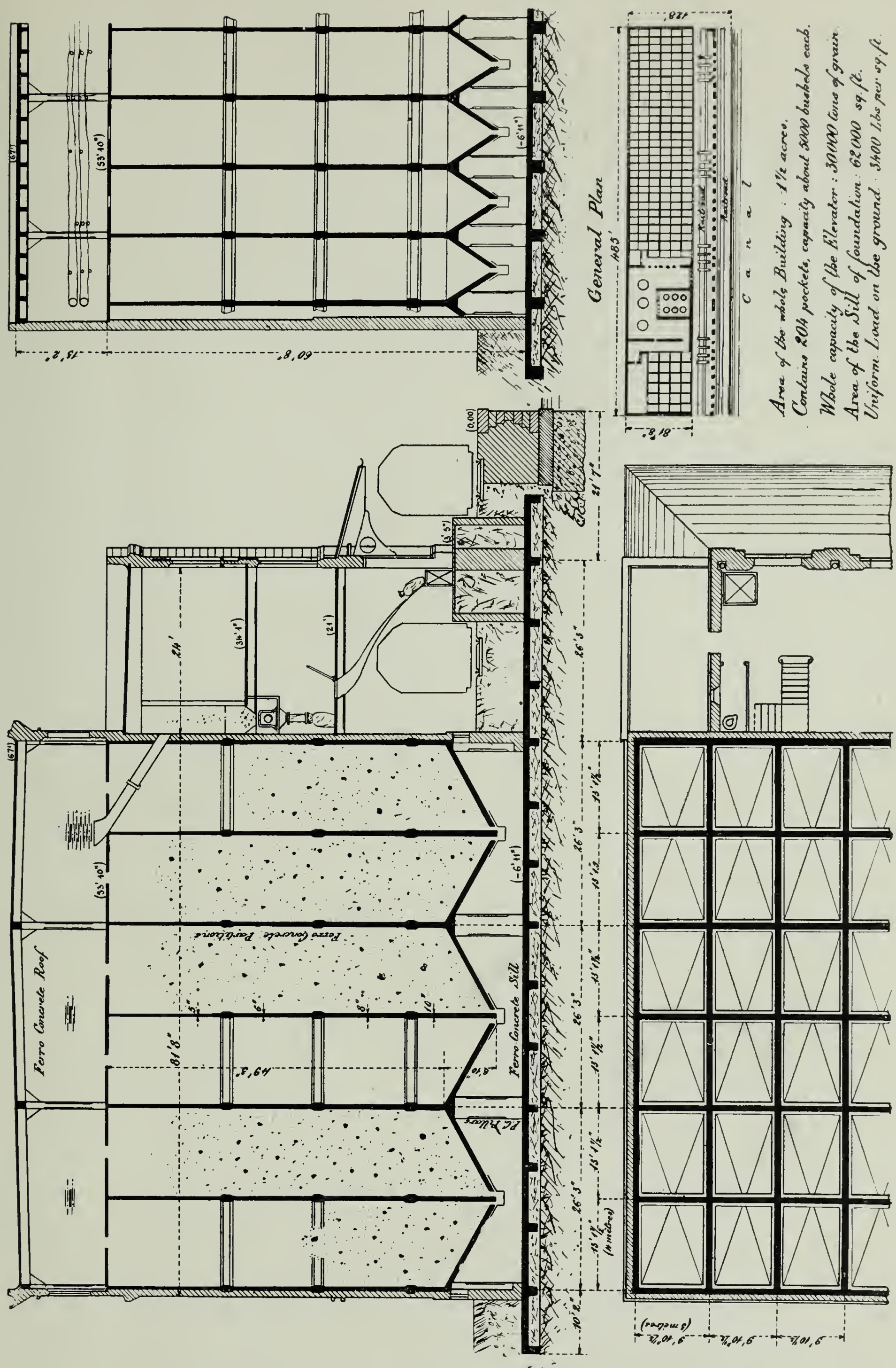

Fig. 33.—Grain Elevator of Genoa.

The Simplon canal has an inner section of 6′ 7″ square and its walls have a thickness of 4″. The side walls are smooth and have a uniform fall of 1, 2 per 1000. The flow of water has a velocity of 6½ feet per second. (Fig. 32.)

The canal is carried on ferro-concrete trestles, which have a height of 16 to 33 feet. They are constructed against the mountain sides as well as upon the rubbish of the plains. The canalization is jointed every 16 feet on the trestles, in order to avoid any fissures which might be produced by expansion and contraction.

Fig. 34.—Coal Pockets, 450 tons capacity.

These joints are filled up with very fine slime which makes them watertight. Moreover, the waste of water that was allowed for was only 1/10 of a gallon per foot and per minute, and it was not attained.

The work was begun on the 1st of April, 1899, and two months later the trestles were finished. The work of canalization was then carried on at the rate of 130 feet per day, with 140 workmen, and the canal of 9800 feet was delivered on the 20th of July and filled on the 22nd. It requires no keeping in repair and will have unlimited duration.

Grain Elevators.

Numerous grain elevators have already been constructed of ferro-concrete, which have all and always given full satisfaction. We will mention among others the mills and elevators constructed at Swansea (England) for Weaver & Co. These elevators have a capacity of 400,000 bushels, a height of 112 feet from the foundations to the flat roof, and the latter is utilized as a cistern to hold about 100 tons. of water. (Fig. 13.)

The elevators of Strasburg contain 330,000 bushels.

The elevators of Genoa are still more considerable and cover a surface of about 1.5 acres. They are composed of 204 rectangular pockets of 57 feet high containing each about 5000 bushels. The partitions are 10″ thick at the base and 5″ thick at the top. (Fig. 33.)

Several coal elevators have also been constructed, especially at the Lens, Louvain, Aniche mines. (Fig. 34.)

3rd.—FOOT BRIDGES AND BRIDGES.

The subject-matter we are entering upon deserves to be fully developed for we are convinced that ferro-concrete will, some day, find in these structures one of its most important applications.

Ferro-concrete bridges unite all the advantages that may be found in wooden, stone or metal bridges, and have none of the principal defects of each of these classes of bridges.

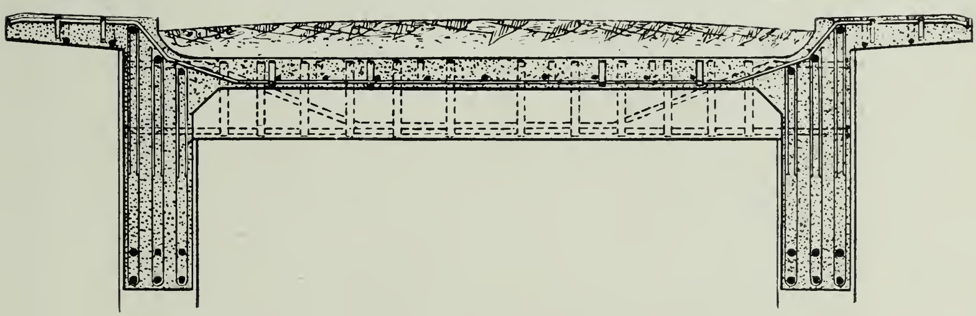

Fig. 35.—Section of a bridge, Hennebique System.

Like wooden bridges, small bridges in ferro-concrete are not very expensive, they are easy to build and do not require preliminary studies nor expensive foundations. They are of excellent service for foot bridges.

Ferro-concrete bridges are indestructible and do not necessitate keeping in repair.[1] They may be given a fine architectural aspect. These are the qualities possessed by stone bridges.

[1] One of the most curious applications of ferro-concrete is to be found in the reenforcement of metallic bridges. The following is given as an example of such work: The engineers of the Orleans Railway Company ascertained recently that a metal bridge at Perigueux was weakened through the oxydation of its members. It was suggested that the damaged structure might be

Fig. 36.—Bridge and Retaining Walls, Quai Debilly, Paris.

Ferro-concrete bridges are lighter than metallic ones and are less subject to vibrations. They lend themselves very easily to the form of skew bridges, which at times are of so great service.

We will speak here of several bridges which were constructed under the control of the service of Ponts et Chaussées of France and which were only given to public traffic after they had withstood the most stringent test conditions.

1. At the Exposition of 1900, the foot bridge which connected the Trocadero palace with the Madagascar exhibit, was built of ferro-concrete, Hennebique system.

2. Subway of the Quai Debilly, Paris, retaining walls and bridge of 46 feet span. (Figs. 17, 36 and 37.)

The bridge over the Quai Debilly formed a continuation of the Iena bridge over the Seine and gave direct access to the Champ de Mars from the Trocadero.

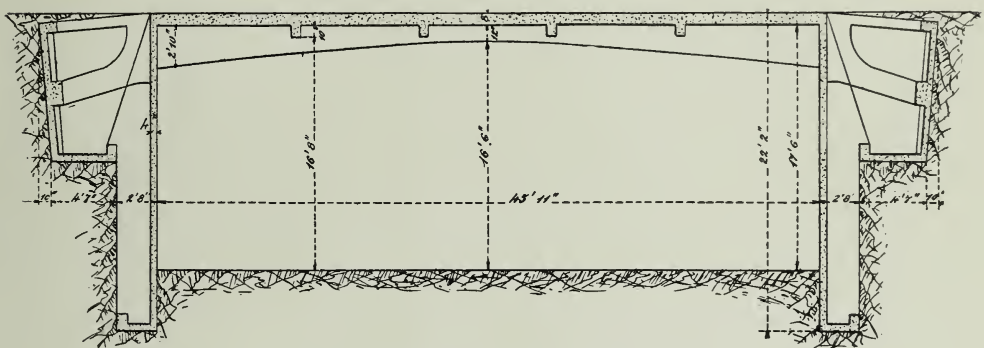

Fig. 37.—Bridge over the Quai Debilly, Paris.

This bridge, with the retaining walls of the depressed viaduct was built of Hennebique's ferro-concrete. It is composed of 12 arched ferro-concrete beams of 46 feet span placed about 8 feet apart; the rise of the arches is 2 feet or 1/23 of the span.

The floor forming the sidewalks and roadway varied in thickness, and is supported on ferro-concrete cross-beams placed at right angles to the main beams. The total width of the bridge is 98′ 5″ and is made up of a roadway 26′ 3″ wide, and two sidewalks each 36′ 1″ wide.

The abutments and foundations, also built of ferro-concrete, are of special design. By this arrangement they are designed to transmit the thrust of the arches evenly, and with as little pressure as may be necessary to the ground behind and underneath the foundation.

The floor was calculated to carry a load of 123 lbs. per square foot, and also rows of carts, each carrying 10 tons on the roadway.

Tests.—The tests of the bridge floor were made on February 6, 1900, in the following manner:

preserved by simply strengthening it with ferro-concrete. This suggestion was accepted as experience had taught, that rusted iron, when imbedded in cement, adheres to it with great tenacity, and at the same time is preserved for an indefinite period. The result attained was all that was desired, and the reconstructed bridge was accepted for service by the government engineers.

1st. A uniform load of 123 lbs. per square foot was distributed over the whole of the bridge, *i. e.*, 46′ x 48′ 5″ x 123 lbs. equals 556,841 lbs., say 248½ tons.

2nd. On the outside bay the load was increased to 185 lbs. per sq. foot, or 50 per cent more than the calculated load.

The girders numbered 1 to 12 showed the deflections given in the table below.

Fig. 38.—Bridge over the Vienne, Chatellerault, France.

Loads	62 lbs. per sq. ft.		123 lbs.	185 lbs.		Load removed by 10hr 35m
Time	11	11.45	4.15	4.45	6.30	11.15
No. of Beam	Deflections in Inches					
1	0.046	....	0.156	0.242	0.218	0.062
2	0.058	0.070	0.183	0.234	0.249	0.066
3	0.066	0.078	0.206	0.234	0.242	0.058
4	0.070	0.082	0.218	0.234	0.238	0.043
5	0.066	0.074	0.195	....	0.210	0.039
6	0.062	0.066	0.179	....	0.195	0.031
7	0.062	0.066	0.183	....	0.195	0.031
8	0.062	....	0.203	....	0.210	0.047
9	0.066	0.086	0.246	....	0.251	0.051
10	0.066	0.078	0.195	....	0.234	0.039
11	0.051	0.066	0.164	....	0.167	0.008
12	0.031	0.039	0.097	....	0.117	0.008

The maximum deflection was ¼ of an inch or 1/2154 of the span. The abutments and foundations stood the test perfectly, there was no settlement or distortions. The diagrams show very clearly the perfect regularity of the increase and decrease of deflection.

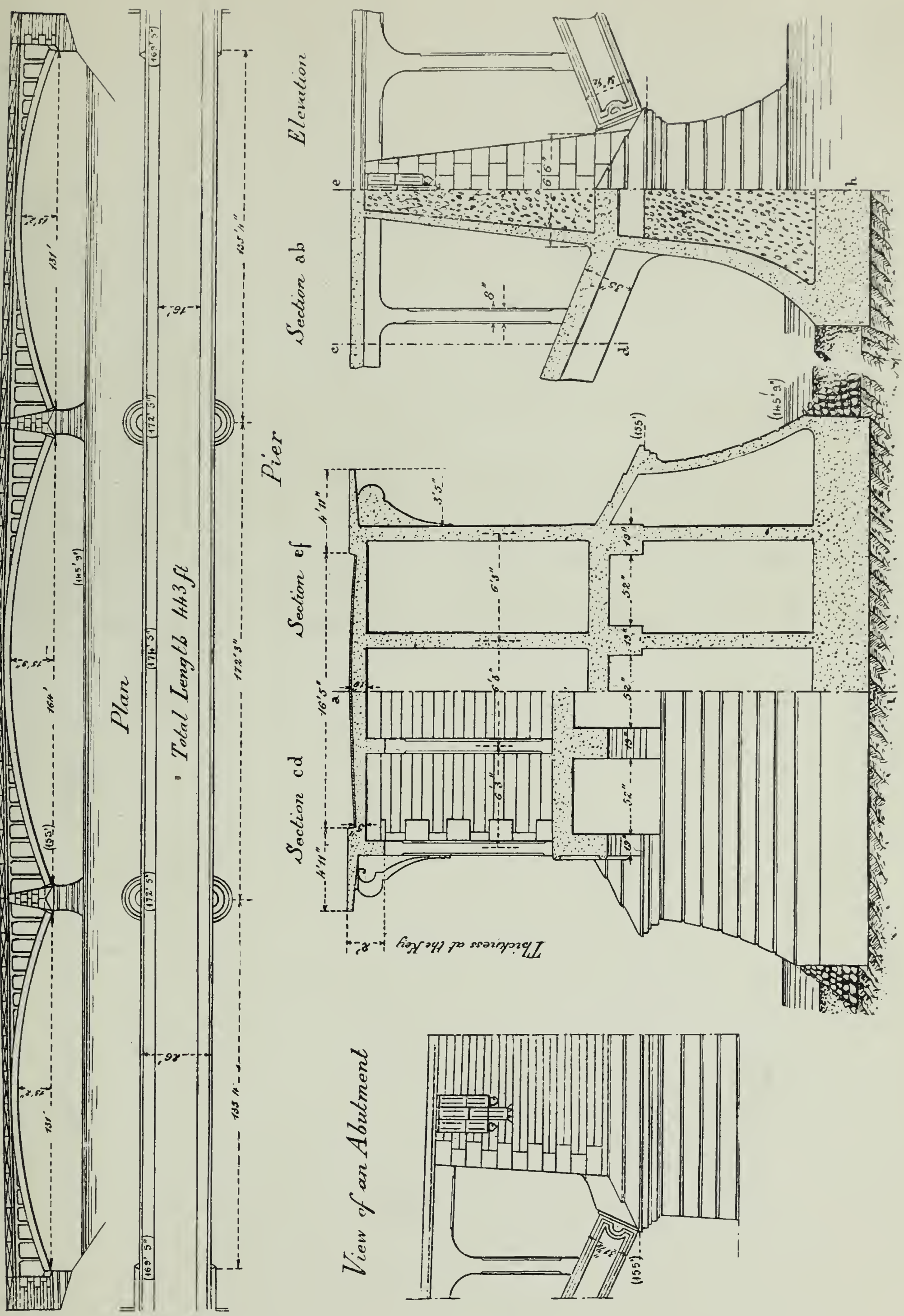

Fig. 39.—Bridge over Vienne, Chatellerault, France.

As a third example we will describe the bridge of Chatellerault over the river Vienne in France. It is the greatest work of art that has been constructed in ferro-concrete, Hennebique system. Foundations, piers, abutments, arches and floor forming all were made of ferro-concrete. (Figs. 38, 39 and 40.)

The total length of the bridge is 443′ and it is composed of three spans, two lateral ones of 135′ with a rise of 13′ and a central one of 164′ with a rise of 15′ 8″. Four arches in ferro-concrete 20″ high, bear, by means of braces 8″ x 8″ the floor of 25′ width; the sidewalks are placed, in part, in cantilever. To give an idea of the lightness of this structure we will say that in the central vault the total thickness at the key is only 28″.

Fig. 40.—Bridge over the Vienne, Chatellerault, France.

The foundations of this bridge were very easily laid, the calcareous rock being found at 5′ below low water mark. The piers and abutments are constituted of four braces corresponding to the arches and connected by a curtain in concrete of 5″ thickness, which gives them their external shape. They are filled in weak concrete of hydraulic lime.

The calculations were based on the supposition that the bridge would have to bear a load due to the passage of two files of two-axled carts weighing 16 tons each; the sidewalks bearing a dead weight of 100 lbs. per square foot.

The centering being placed and the foundations ready, the concreting was begun on the 15th of August, 1899; it was completed by the 5th of November, and the centering was removed on the 15th of December following.

The bridge was then subjected to a series of trials under the direction of Engineer Aubin of the Ponts et Chaussées.

The tests by dead weight were conducted in the following manner: each bay was loaded over its total length, then on each half, then on its median part. This load was formed of moist sand and the rate of 165 lbs. per square foot on the road bed and 123 lbs. per square foot on the sidewalk.

The official report of the trials by Engineer Aubin says that:

"The maxima of depressions were of ¼″ for the arch of the left shore, 7/32″ for the arch of the right shore and 13/32″ for the central arch. The mean proportion for the lateral arches 1/7300 of the bearing and for the central arch only 1/5000. When the overloads were removed and the bridge completely cleared the arches returned very exactly to their original position."

The bridge was tested with a moving load composed of:

1 steam roller of 16 tons.

2 two-axled carts of 16 tons.

6 s'ngle-axle carts of 8 tons which, together with the teams, gave total weight of 40 tons passing simultaneously on the bridge, whose sidewalks bore, in addition, a load of 80 lbs. per sq. foot. More than that, 250 infantry-men were made to cross the bridge in a body, first at cadenced step, then in double-quick time. (Fig. 38.)

After this the steam roller was passed over the platform, upon which cleats of wood, 2″ thick were strewn in order to produce a series of shocks.

We cannot give, in this sketch, the results of all the trials that this ferro-concrete bridge victoriously withstood.

The maximum of depression attained did not exceed 1/9000 of the length of the arches and the deformations of the arch with regard to its mean line always remained inferior to those caused by the dead-weight tests.

There never was any permanent deformation.

But the most remarkable fact that was ascertained in the course of these trials was that the three arches were united by a sort of solidarity, so that the load which caused a flection in one of them excited at the same time a raising up of the contiguous arch.

We are right, therefore, when we say that a structure in ferro-concrete, Hennebique system, forms a monolith, without joints, such as are seen in bridges of masonry work and without scarfings like those of metallic bridges.

Let us end here by saying that the dead weight of the bridge of Chatellerault, all told, is only 250 lbs. per square foot, and that it cost the city less than 200,000 francs to construct.

One will be possibly astonished to see how numerous are the applications of the Hennebique system of ferro-concrete. The explanation is simple. The inventor has been able to interest in his system of construction a great many engineers, architects and builders who have given him their ideas and have become his collaborators.

When the American mind will have grasped the Hennebique system we feel certain most wonderful constructions will prove its merits and advantages to an intelligent public.

The best ending for this pamphlet will be the following words of Geo. S. Morrison, an eminent construction engineer of Chicago, who sounded the keynote on the subject before the Western Society of Engineers when he said in substance:

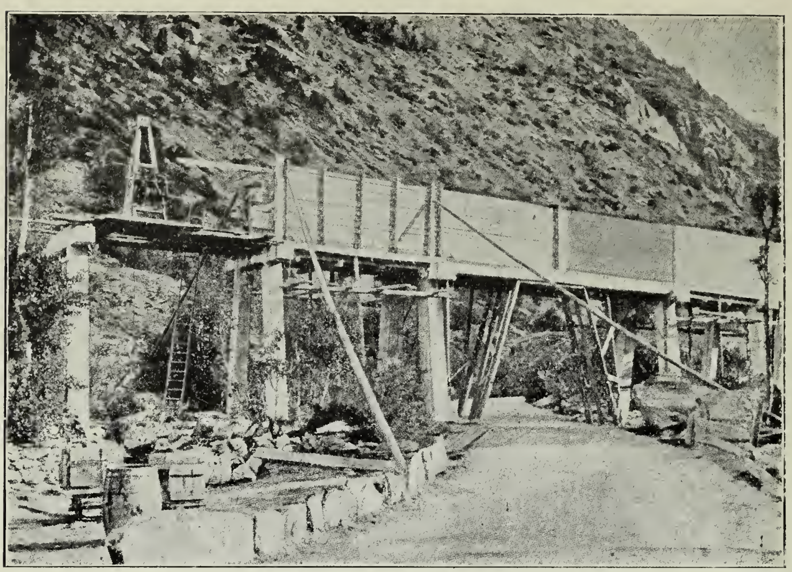

Fig. 41.—Construction of the Canalization of the Simplon.

" I believe we are only at the beginning of concrete construction, and if the results can be obtained with concrete structures carrying light metal structures imbedded within, the time will come when this will be the one correct method of building. A concrete mass with a metal skeleton in which the concrete absolutely protects the metal from corrosion is what we may reasonably expect to-day—a concrete as good as the majority of natural stone, we ought sooner or later be able to produce—is the ideal material for buildings. . . . . .

It would be immensely better than a steel skeleton covered with a thin layer of terracotta exposed to the oxydizing influence of the atmosphere.

The time will come when artificial stone buildings constructed in this manner will be more used than anything else."

HENRI KAMPMANN,

INGÉNIEUR DES ARTS ET MANUFACTURES.